Comparing Manned Aerial Surveys to Unmanned Aerial Surveys for Cetacean Monitoring in the Arctic: Field Report

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And

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LONG-TERM GOALS

Manned aerial surveys from fixed-wing aircraft have been used successfully for decades to achieve diverse scientific and wildlife management goals. Aerial line-transect surveys for marine mammals collect data that can be used to estimate density or abundance and investigate habitat use and behavior (Buckland et al. 2001, Garner et al. 1999). NOAA Fisheries, the Department of the Interior, the North Slope Borough Department of Wildlife Management, and other agencies have been involved in many marine mammal research flights in the Arctic designed to provide information on animal density and distribution important to both the agencies and to North Slope Residents. These long-term datasets provide agencies with information they need on the status of the marine mammal populations.

Although decades of valuable research, monitoring, and mitigation activities have been conducted successfully from manned aircraft, and will continue to be used in the foreseeable future, these survey platforms do have limitations. First, there are risks inherent in manned aerial operations that must be mitigated to reach an acceptable level of safety for the survey team. Second, observer discomfort or fatigue caused by extended periods of time aboard the aircraft can affect data collection. Third, manned aircraft, like any survey platform, have the potential to disturb wildlife. Lastly, manned aircraft burn a considerable amount of fuel, resulting in high costs and consumption of non-renewable resources.

Marine mammal aerial surveys conducted by UAS may not be affected by some of the limitations of manned aircraft and could be a reliable, effective, and efficient way to collect data to address questions in marine mammal ecology and management. UAS have only recently been used in ecology and wildlife management, but their use is growing rapidly (Watts et al. 2010, Sarda-Palomera et al. 2012, Anderson and Gaston 2013), including marine mammal research applications (Koski et al. 2009, Hodgson et al. 2010, Koski et al. 2010, Hodgson et al. 2013). The use of UAS to survey pinnipeds is still in its infancy, but it has been successfully used to collect images of Arctic ice seals (Cameron et al. 2009, Moreland et al. 2015) and Antarctic pinnipeds (Goebel et al. 2015) and tested for Steller sea lions (Fritz 2012). Hodgson et al. (2013) conducted strip-transect surveys for dugongs in Australia using a ScanEagle® UAS with a digital SLR camera payload and concluded that this type of UAS has “great potential as a tool for marine mammal aerial surveys.” Strip-transect surveys are based on the assumption that all animals within the strip are detected.

While unmanned aerial systems (UAS) have great potential, the specific data and sampling requirements for research have not been fully tested, particularly in the Arctic. Existing UAS technology integrated with a digital camera payload needs to be evaluated to determine how well it performs relative to conventional manned aerial surveys to collect data on cetaceans. The balanced use of manned and umanned technology for implementing and evaluating management of wildlife is a priority, and this arctic mission is one of the first dedicated experiments specifically designed to understand the advantages and disadvantages of using UAS relative to manned aircraft to collect data for estimating marine mammal density.

Relevance to the Bureau of Ocean Energy Management and the Office of Naval Research

The Bureau of Ocean Energy Management (BOEM) and the Office of Naval Research (ONR) Marine Mammals and Biology Program (MMB) both support research and technology development related to understanding the distribution and abundance of marine mammals in key areas. In addition, it is important for both agencies to quantify the number of individuals of each species that could be affected by a proposed activity; the amount of the proposed activity conducted within biologically important areas, such as feeding grounds and migration pathways; the age and sex class of affected species; and the types of effects to individuals and populations these activities may have.

Aerial and vessel-based line-transect surveys are widely used and broadly accepted methods for collecting data to study spatiotemporal patterns in cetacean density, abundance, distribution, habitat use, and behavior and for mitigating and monitoring the effects of military activities and other anthropogenic activities to ensure environmental compliance. However, these methods are time and labor intensive and could be unsafe for human observers to implement, especially during naval activities or in areas far offshore. Strip-transect surveys conducted by UAS have the potential to replace manned aerial and shipboard line-transect surveys for some combinations of species/populations, time periods, and areas, thereby minimizing risks to human life, reducing disturbance to wildlife, and possibly decreasing the logistical complexity associated with data collection. Furthermore, with reliable automatic image detectors, the labor required to process the survey data could decrease considerably, making imagery data collected by UAS valuable for mitigating risks to marine mammals. As survey and analytical efficiency increase, financial burdens decrease.

Before BOEM, the Navy, and NOAA Fisheries can accept UAS surveys in place of, or as a supplement to, conventional aerial survey methods, the performance of UAS relative to human observers in manned aircraft must be understood. This project, Arctic Aerial Calibration Experiments (Arctic ACEs), which was funded by BOEM, the Navy, and NOAA, addresses this critical question. We partnered with Shell Oil and the North Slope Borough Department of Wildlife Management due to our shared interest in understanding the performance of UAS surveys relative to surveys conducted by manned aircraft. At the end of the project, we intend to provide recommendations on the types of cetacean study objectives that likely can be met by UAS currently and in the near future, describe improvements in UAS technology and imaging systems required to effectively study cetaceans in the Arctic (and elsewhere), and recommend adaptations to the traditional analytical processes for estimating density.

OBJECTIVES

We shall evaluate the ability of UAS technology (i.e., platforms, payloads, sensors, and software) to collect data to detect cetaceans, identify species, estimate group size, and identify calves and compare those results to conventional aerial surveys conducted by human observers in fixed-wing aircraft as part of the Aerial Surveys of Arctic Marine Mammals (ASAMM) project. Data collected from the UAS will be used to estimate cetacean density and other parameters in the survey area and to compare these values to analogous values obtained using data from the manned aircraft. This evaluation will enable us to provide recommendations for

the types of cetacean study objectives that can likely be met by UAS currently and in the near future, describe improvements in UAS technology and imaging systems required to effectively study cetaceans in the Arctic (many of which will be applicable to cetacean surveys conducted elsewhere), and recommend adaptations to the traditional analytical processes for estimating density. Our overarching objective is to conduct a 3-way comparison of data and derived statistics from the following:

- Observers in the manned aircraft;
- Digital photographs from cameras mounted to the manned aircraft;
- Digital photographs from cameras mounted to the unmanned aerial vehicle (UAV).

Our specific objectives include:

1. Collect digital photographic data from small UAS (sUAS) during strip-transect surveys of cetaceans in the Arctic.
2. Collect digital photographic data from the ASAMM aircraft concurrently with line-transect ASAMM surveys.
3. Evaluate the ability of trained observers/photo-interpreters to detect marine mammals in photographic images.
4. Evaluate existing software to detect cetaceans in aerial digital photographic data collected from manned and unmanned aircraft.
5. Estimate trackline detection probability for marine mammal observers participating in the ASAMM project.
6. Estimate the trackline detection probability for photo-interpreters from imagery collected during the ASAMM project.
7. Compare the performance of manned and unmanned aircraft surveys based on metrics such as the following: i) number of sightings made by each platform, including false positive and false negative rates; ii) ability to identify sightings to species, estimate group size, and detect calves; iii) precision and bias of the resulting density estimates; iv) relative efficiency of each platform, measured by length of trackline and duration of survey and analytical effort required to achieve target precision in the density estimate or to compute other derived parameters; v) survey and analysis cost; and vi) fuel consumption.
8. Provide recommendations to the Navy, NOAA Fisheries, and BOEM about the types of cetacean study objectives that can likely be met by UAS technology now and in the near future.
9. Describe improvements in UAS technology and imaging systems required to study cetaceans in the Arctic (and elsewhere).
10. Recommend adaptations to the traditional analytical processes for estimating density.

APPROACH

Research team

The project was initiated and managed by principal investigators (Angliss and Ferguson) from the National Marine Mammal Laboratory, Alaska Fisheries Science Center, NOAA Fisheries. The PIs and others at NOAA developed the survey design, purchased the payload, designed and evaluated flight tests of the payload, led the development of the concept of operations, ensured that all Marine Mammal Protection Act and local land use permits were obtained, and ensured that both local pilots and the local community were aware of the project. In addition to the NOAA PIs, NOAA staff and contractors who played a key role in the project included:

- CAPT Phil Hall (OMAO) – advised on COA preparation and beyond visual line-of-sight flight operations; served as the NOAA liaison with the FAA;
- Van Helker (Oceans Associates, Inc) – drafted documents needed for clearance within NOAA and the Navy; NOAA lead for shipboard integration on the NOAA Ship *Fairweather*; project liaison on the *Fairweather* during field operations;
- Amy Kennedy (Joint Institute for the Study of the Atmosphere and Ocean – JISAO) – lead the selection and pre-field season evaluation of the camera payloads; lead photographer during field operations.

The Naval Surface Warfare Center Dahlgren Division (NSWCDD) was responsible for managing all aspects of the UAS operations. The NSWCDD team submitted the request for a Certificate of Authorization to the Federal Aviation Administration (FAA) for clearance to conduct beyond visual line-of-sight (BVLOS) operations and all paperwork (e.g., risk assessment) needed to obtain clearance from the Navy. They integrated and tested NOAA's camera payload, were responsible for most logistics for the field project, and conducted UAS flights to collect imagery between August 26 and September 6, 2015. While in the field, the team was responsible for all pre-flight and post-flight tasks, including all maintenance needed to ensure that the full UAS system (ground control stations, communications systems, platforms, and payloads) were ready to fly each day, posting NOTAMs, and post-flight reporting. The responsibilities of NWSCDD staff, contractors, and associates are as follows:

- Site Lead/Airboss
- ScanEagle® Pilots in Command (PIC)
- Payload Integration Engineer
- Managerial Support
- ScanEagle® Launch and Recovery Technician
- ScanEagle® Subject Matter Expert / ScanEagle® Launch and Recovery Technician

We worked closely with Todd Sformo of the North Slope Borough Department of Wildlife Management (NSBDWM) because of the agency's interest in the use of new technology to study large whales and to ensure that our project could be successfully integrated into the Barrow community. The NSBDWM provided guidance about key individuals and organizations to contact to be certain that the project would not interfere with important Alaska Native subsistence harvest activities.

The ASAMM team conducted the manned aerial surveys needed for comparison to the UAS surveys funded under this award. ASAMM is funded and co-managed by BOEM and conducted by AFSC, and led by Megan Ferguson and Janet Clarke (Leidos). The ASAMM database extends back to 1979 and represents one of the longest-running aerial surveys of marine mammals in the world. During the UAS field season, the ASAMM pilots and marine mammal observers were:

- Amelia Brower (JISAO) – ASAMM Flight Team Leader
- Stan Churches (Clearwater Air, Inc) – PIC
- Vicki Beaver (Ocean Associates, Inc) – Marine Mammal Observer
- Greg Pfeifer (Clearwater Air, Inc) – Second in Command
- Karen Vale (Ocean Associates, Inc) – Marine Mammal Observer

Study area

Rationale for operating from Barrow, Alaska

UAS aerial surveys were conducted in airspace in the northeastern Chukchi Sea and western Beaufort Sea (Figure 1). The study area is located approximately 12-60 nmi from shore on either side of Barrow, Alaska. This area was selected for UAS operations for three reasons. First, the study area lies within an area where the FAA plans to establish permanent operational areas and corridor routes (for access to coastal launch sites) in the Arctic for the operation of small UAS. We anticipated that this emphasis would enhance our chances of receiving FAA permission for beyond visual line-of-sight flights needed for the project. Second, large cetaceans, particularly gray whales and bowhead whales, are reliably found in high densities near Peard Bay and Barrow Canyon, respectively, during the open water (ice-free) season, which occurs from July to October. High densities of cetaceans are preferred in order to obtain the sample sizes (number of sightings) required to derive robust conclusions about the relative performance of manned aircraft and unmanned aircraft systems in a reasonably short amount of time. Third, the study area is located in international airspace, offshore of the coastal corridor where aircraft frequently transit between villages on the North Slope of Alaska. Operating in this low density traffic area increases the safety margin for the project by decreasing the probability of encountering other airspace users.

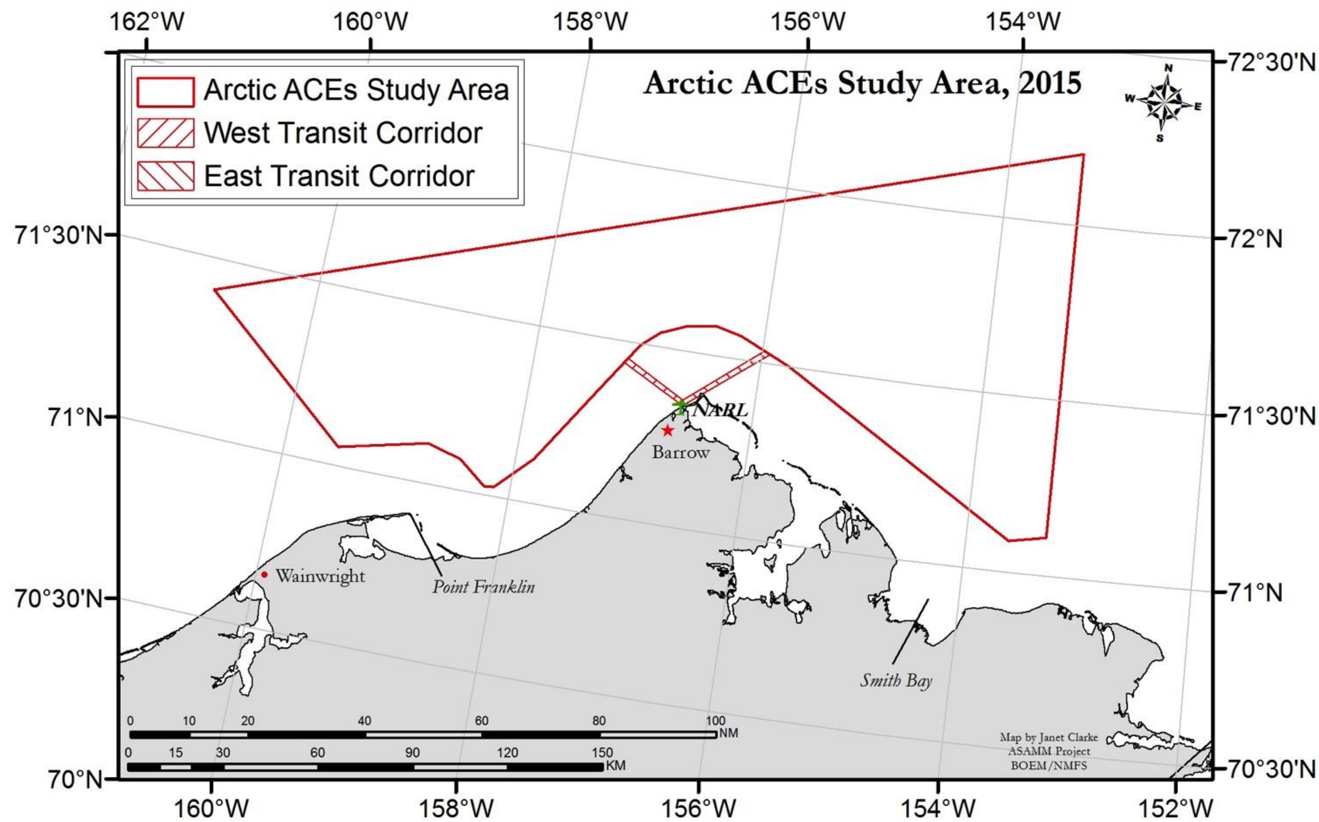


Figure 1. Study area for the Arctic Aerial Calibration Experiments project.

The project team considered operating out of Wainwright, Alaska, due to the proximity of Wainwright to an area of high density of gray whales near Peard Bay. Conducting the project out of Wainwright was less favorable due to the high cost of chartering a commercial C130 that would be needed to transport the UAS equipment and because of the high cost and limited availability of launch/retrieval sites in Wainwright. Barrow afforded both a sufficiently large runway to allow the Navy C130 to transport the UAS gear at no cost to the project and did not require fees for access to the launch/retrieval site.

Weather during the late summer and early fall in the Arctic can range from cloud-free and sunny to snow, sometimes within the same day. Based on many years of experience conducting manned aerial surveys in the Arctic, the team expected to experience near-freezing and below-freezing temperatures, high winds, fog, low ceilings, various types of precipitation, and potential for the UAV to experience both structural and carburetor icing (which is more likely to occur with high relative humidity and low ambient temperatures). Based on the number of flight days flown historically by the ASAMM teams, this project expected to be able to conduct flights on 5-6 days during a 17-day field season planned to occur between 14-31 August 2015.

Equipment

ScanEagle® UAS

The Insitu ScanEagle® UAS was selected for this study due to its strong airworthiness history and payload capacity. This platform was used successfully from the NOAA Ship *McArthur II* in 2009 to collect imagery of ice-associated seals in the Bering Sea (Moreland et al. 2015).

The mission used two ScanEagle® UAS manufactured by Insitu, Inc. (Figure 2). All pilots were trained by Insitu and had Letters of Authorization designating them as approved ScanEagle® UAS pilots by a US Navy Squadron . ScanEagle® dimensions and performance characteristics are included in Table 1.

Figure 2. ScanEagle**®** on launch at Naval Surface Warfare Center – Dahlgren Division

Table 1. Performance characteristics of the ScanEagle® UAS.

Performance	
Maximum horizontal speed	80 knots
Cruise speed	50-60 knots
Maximum service ceiling	19,800 ft
Endurance	24 hours
Dimensions	
Wing span	10.2 ft
Length (Dual bay configuration)	6.5 ft
Weights	
Empty structure weight	30.9-39.68 lbs
Maximum takeoff weight	48.5 lbs

Figure 3. ScanEagle® UAV

System description. The ScanEagle® UAS is configured for land- or sea-based operations, and includes the aircraft, launcher, retrieval system, Ground Control Station (GCS), software, and auxiliary equipment. The platform is flexible, expandable, and can be quickly reconfigured in the field.

Air vehicle. The ScanEagle® UAV is built to carry customer-supplied sensors and processors, and to provide a flexible aerial platform with power, communications, and volume for additional payloads. The aircraft is designed to handle multiple, highly persistent sensing roles including Intelligence Surveillance and Reconnaissance (ISR) and communications relay.

The ScanEagle® UAV is a long endurance aircraft composed of modules that are replaceable at the field site. The ScanEagle® UAV (Figure 3) is a tailless aircraft that features a high aspect ratio swept wing. It has a rear-mounted engine driving a pusher propeller. Two sets of elevons on the wings provide pitch and roll control, with rudders on the winglets at the wing tips for directional control.

Ground control station (GCS) and software. Flight operations with the ScanEagle® are controlled with a stationary (land based) or mobile (ship based) GCS. GCS software includes operator interfaces for preflight checks, operating, flying, and monitoring multiple aircraft on independent missions.

*Launch system.*_The SuperWedge® Laucher was used to launch the aircraft (Figure 2). The launcher is charged by an attached air compressor. The UAV is launched by removing the safety pin and then the catapult is manually activated using a pull trigger. On firing, the launcher accelerates the UAV, and at the end of the rail, the UAV is launched at takeoff speed.

Figure 4. Skyhook**®** retrieval system, Barrow AK.

Retrieval system. The SkyHook® retrieval system (Figure 4) captures the UAV. The SkyHook® system uses a GPS receiver and antenna to make an accurate approach via data relayed through the control station. The aircraft is captured by flying into a rope suspended approximately 45 feet above the surface. A hook on the wingtip catches the line and quickly stops the aircraft.

Digital camera payload

The UAV was equipped with a Nikon D810 high-resolution digital camera capable under ideal conditions of providing a minimum photographic ground resolution of 7 cm/pixel and a minimum photographic strip width of 400 to 600 m at 1000 m altitude. Each camera was equipped with a 20 mm Nikkor f2.8 lens. The Nikon D810 and lens were chosen for a number of reasons:

- The predecessor to the D810, the Nikon D800, had been used successfully in similar projects undertaken by LGL. The D810 contained all of the same features as the D800, but allowed for an ISO as low as 32 compared to ISO50 on the D800.
- The 36.3 megapixel sensor provided for a 576 m swath width at survey altitude of 1050' with a 20 mm lens.
- The camera body had slots for both a CF and SD storage card, enabling us to put 1 TB of storage in the camera. 1 TB of storage translates to roughly 10 hrs of flight time.
- Initially, a 21 mm Zeiss Distagon lens was chosen for the UAS camera in order to be consistent with the manned aircraft payload. Unfortunately, the weight and length of the Zeiss lens exceeded the UAS carrying capacity. The 20 mm Nikkor lens is shorter, lighter, and would allow for a greater swath width than the Zeiss.

Prior to integration into the ScanEagle® system, the camera and lens setup was tested on the ground to ensure that each component was functioning properly, was capable of delivering the resolution specified by the manufacturer, and was free of defects/aberrations that would be visible in the images. Images were taken at varying distances from an image resolution test target and with a range of settings similar to what may be used in the field. The images were then analyzed to assess resolution, focus, and uniformity.

The Nikon D810 was powered over the ScanEagle® expansion power circuit. During each picture, the amperage draw onboard the ScanEagle® would spike, allowing the operator to confirm the camera was functional and had the proper picture interval.

<u>Digital camera payload flight-testing</u>

The Nikon D810 and 20 mm Nikkor lens was flight tested at NWSCDD on 21-22 July 2015. The UAS overflew a tri-bar calibration target at pre-determined altitudes in order to assess the accuracy of the camera system. In addition, the tests were necessary to ensure that the pilots could determine whether the camera was firing. The bars on the calibration target ranged from 0.5 cm wide to 10.8 cm wide. During the test flights, images taken at 1050 ft AGL and 60 kts showed an image resolution of 6 cm (Figure 5).

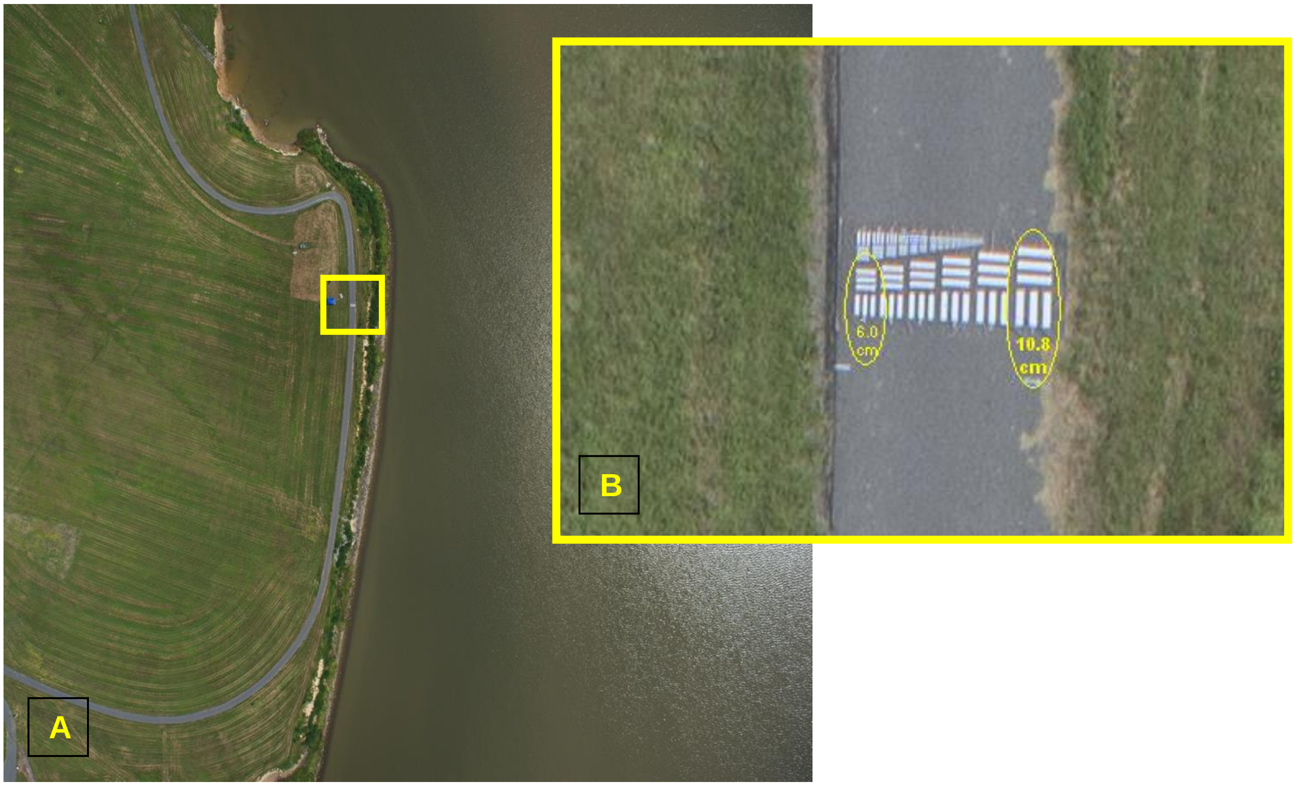


Figure 5. Image A was taken from the UAS during the test flight in Dahlgren, VA at 1050 ft AGL and 60 kts ground speed. Image B shows the calibration target at 300% zoom, with circles around the 6 cm wide and 10.8 cm wide calibration tribars.

<u>Temperature/humidity sensor</u>
At ONR's request, the UAV also carried an ASAPS sensor funded by ONR and designed by PEMDAS that collects and transmits information on observed temperature and relative humidity. The addition of this sensor was helpful, as it provided real-time, streaming data on environmental conditions, particularly potential for icing conditions, which might impact the flight. The information from the sensor was viewed on a laptop that could be seen by the UAS team, and the information was used to modify flight plans during the flight.

Field operations

The shore team (5 staff from Dahlgren; 3 staff from the AFSC) was based at the runway north of the Naval Arctic Research Laboratory (NARL), approximately 5 miles north of Barrow, Alaska. Portable Arctic Oven tents were used to shelter the GCS, the UAS, and the survey team. The tents, along with the launch and retrieval equipment, were positioned near the defunct NARL runway in front of the northernmost hanger (Figures 6-8).

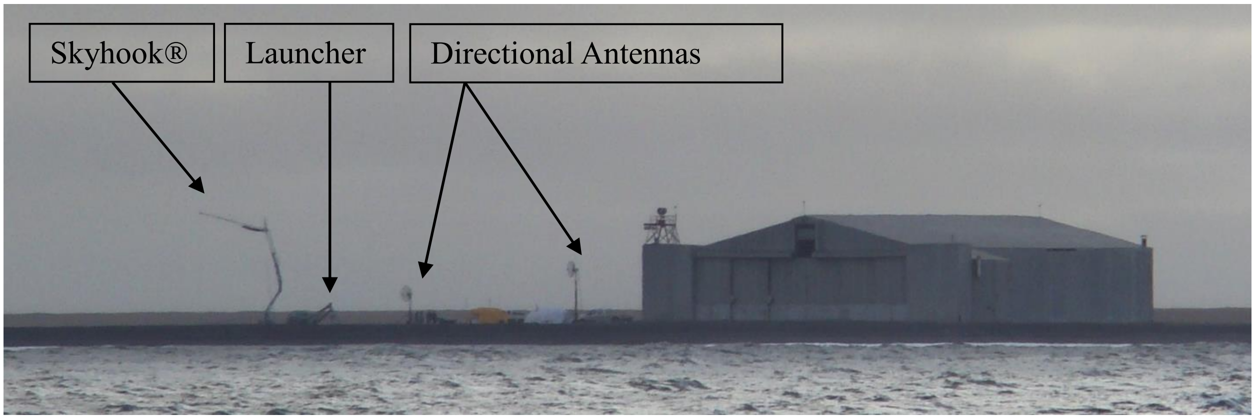


Figure 6. View of ScanEagle® UAS ground equipment at NARL from the NOAA Ship *Fairweather*

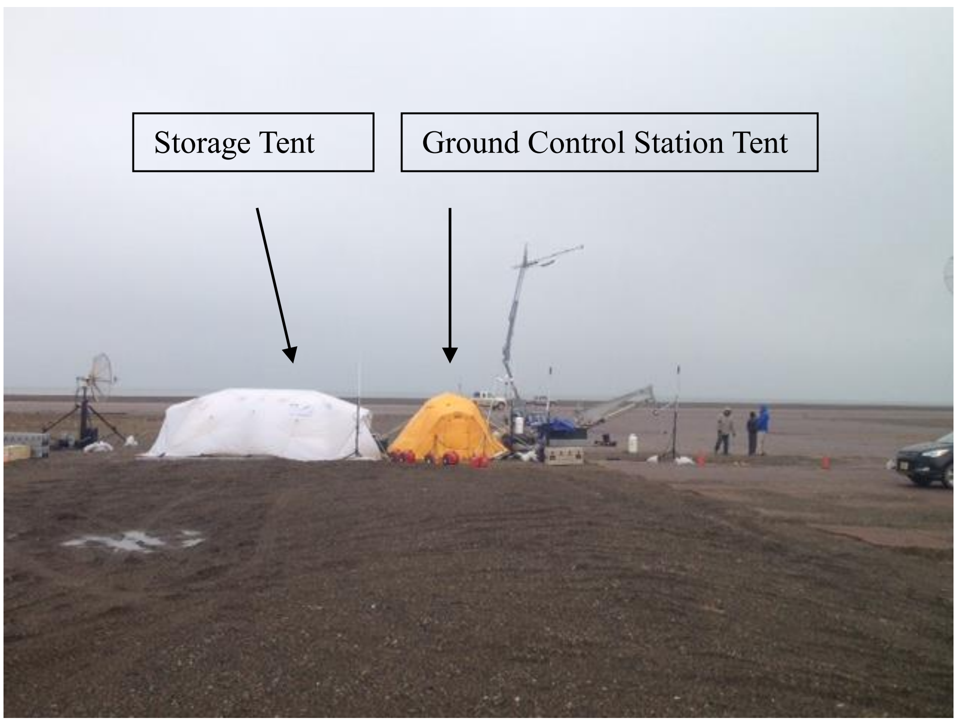


Figure 7. ScanEagle® UAS ground equipment

Figure 8. ScanEagle® on final approach

NOAA Ship *Fairweather* was positioned in the study area from August 19 through August 30 to enable full UAS coverage of the study area. The ship-based team (1 staff from Dahlgren, 1 staff from the AFSC) departed aboard *Fairweather* from Nome on August 17. The ship was available to increase the situational awareness and radio communication range of the UAS pilots and provide aid in recovering the airframe in the event of a water landing. When not committed to supporting the UAS project, the ship's crew conducted hydrological surveys of the areas near Barrow, and deployed Navy wave-gliders, ensuring that vessel time in the area would be optimized.

The ScanEagle® UAVs were launched and recovered from the shore-based station at NARL and accessed the offshore study area located in international airspace through one of two transit corridors. The UAV remained at or below 400 ft MSL (121 m) while inside the corridor. Once in the offshore study area, the UAV increased altitude to 1,000 ft MSL (303 m) and flew pre-programmed fine-scale (2.56 miles; 4.75 km apart) transects, collecting high-resolution digital photographic strip-transect data with a Nikon D810 with a 20 mm Nikkor lens every 100 m distance over water. The UAV remained within communication line-of-sight of a GCS (50-70 nmi). The pilot monitored the onboard video and PEMDAS ASAPS sensor output and altered course as necessary to avoid precipitation or clouds. Once UAS operations were complete on a particular day, the UAV descended to < 400 ft MSL (121 m) while still in international airspace offshore and entered the transit corridor inbound for recovery at NARL.

The ASAMM field team provided the manned aircraft support for the project. ASAMM observers collected both visual line-transect data on marine mammals and relevant environmental conditions, according to ASAMM survey protocols, from a fixed-wing, twin-engine turboprop Turbo Commander 690A. A Nikon D810 with a 21 mm Zeiss lens was

installed in the aircraft by Shell contractors working for LGL, and collected images every 3 seconds. Additional camera systems were mounted in the aircraft to expand the effective swath width, but the primary comparison between imagery will be between imagery collected with the downward-looking D810 cameras in both the ScanEagle® and the Turbo Commander.

The team contracted a local company to provide both polar bear monitors and night security. Polar bear monitors were on site when a polar bear had been seen nearby in the previous 24 hours, or when the team expected to conduct UAS flights. Night security was provided by a local corporation for part of the project, and by a Navy contractor when project funds were no longer available.

<u>In-field camera calibration</u>

At the beginning of each flight, the manned aircraft and UAS overflew one calibration target (Figure 9) positioned on the NARL runway near the field site, at 400 ft (UAV) and 1000 ft (manned aircraft) MSL. In addition, the UAV overflew the *Fairweather* at 1000 ft MSL on the first flight day (8/26). The *Fairweather* affixed a calibration target (Figure 10) to the bow of their vessel, which allowed for at-sea payload calibration. Assessment of the 400 ft and 1000 ft images showed the resolution did not meet our acceptable minimum resolution requirements. To compensate for the blur associated with these images, we increased the ISO and shutter speed and re-focused the lenses for all subsequent flights. These changes resulted in visibly higher resolution than the previous flight, yet the resolution was still poorer than the 3.02 cm we expected at 400ft. We could not differentiate between the largest bars on the shore based calibration target, which were 3.8cm wide.

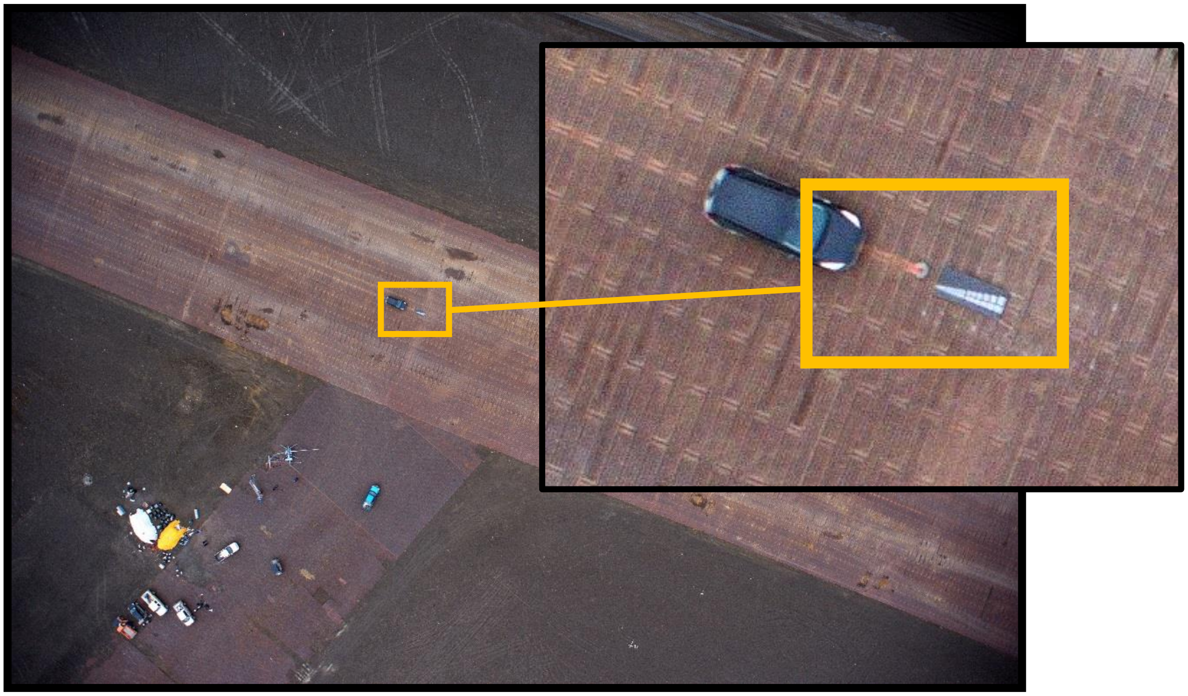


Figure 9. Calibration target at the NARL field site. Yellow boxes indicate the location of the calibration target, and a zoomed insert of the target. The largest bars measure 19 cm by 3.8 cm on the shore-based target, yet none of the calibration bars are distinguishable.

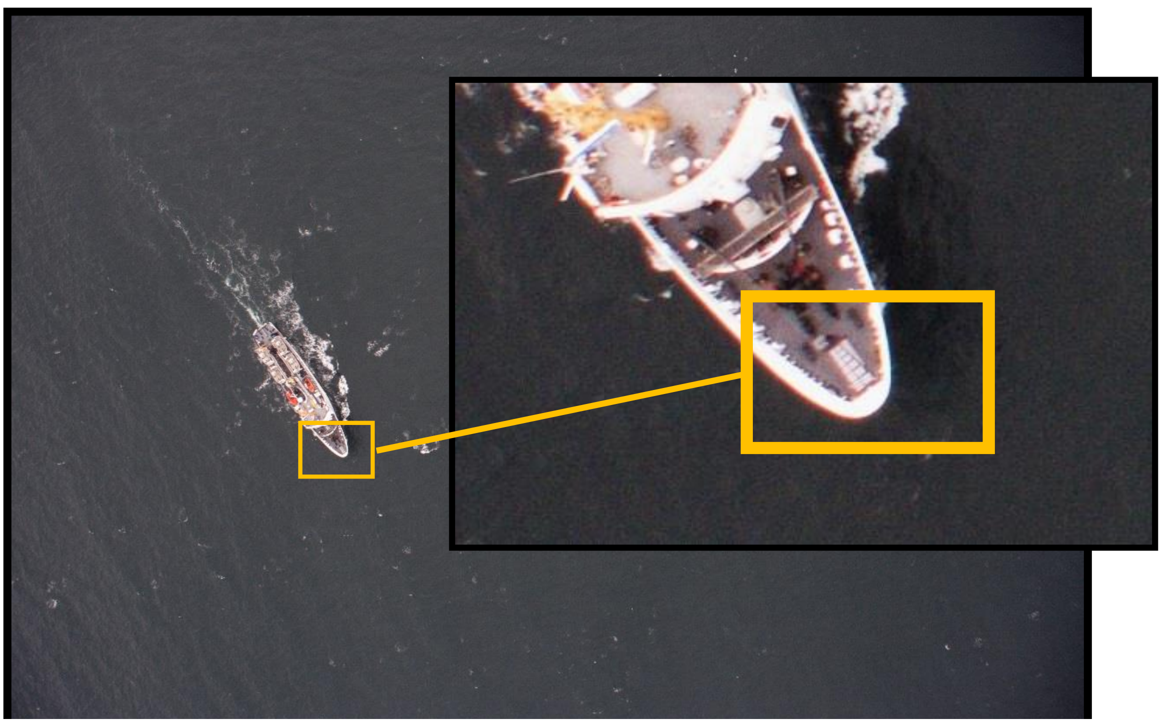


Figure 10. Calibration target on the NOAA Ship *Fairweather*, photographed from the UAS at 997 ft MSL. The yellow boxes indicate the location of the calibration target, and a zoomed insert of the target. The largest bar measures 53.9 cm by 10.8 cm, yet none of the calibration bars are distinguishable.

Aerial survey sampling design

NOAA Fisheries considers abundance estimates with a coefficient of variation (the standard deviation relative to the population size) of less than or equal to 0.3 to be the desirable level of precision appropriate for making management decisions. Statistical analyses of existing aerial survey data of cetaceans in this study area suggested that a coefficient of variation of 0.3 in the estimated density of gray whales may be achieved by analyzing the data collected over approximately 50 hours of UAS flight time. In order to collect enough data for a robust analysis, we planned to conduct daily flights of up to 14 hours in duration on two UAVs simultaneously over a 17-day period.

Coordinating UAV and manned aerial survey flights

The survey design assumed that the UAV and manned flights would be synchronized in time and space to obtain independent, replicate samples of whales. There is some risk inherent in deliberately conducting flights of manned and unmanned aircraft geographically close to each other and at the same altitude. General flight plans were discussed each morning at the 0800 hrs (local) meeting. In-flight safety was ensured by developing procedural methods by consensus among the UAS and Clearwater pilots and science leads for the two field teams, and by using technological methods required by the FAA. Technological methods included Traffic Alert and Collision Avoidance System (TCAS) for the manned aircraft, which alerts pilots of nearby aircraft that are a possible collision threat based on their range, altitude, and bearing. NOAA used an air traffic awareness tool, which allowed the UAS team to detect aircraft in the area. The two aerial survey teams flew successfully in the survey area, but there were sufficient difficulties with communications between teams that both teams decided further spatial or temporal separation was necessary after the flights on September 1. Flights on September 2 were conducted by both aircraft in the same geographic area but were offset by time: the manned aircraft conducted flights first, and then departed the area when the UAV arrived.

Authorizations

FAA Certificate of Authorization (COA): The NSWCDD applied for and received a COA that authorized flights for this project. This COA was notable for the following reasons:

- It authorized routine beyond visual line-of-sight flights of a UAV in the National Airspace System;
- It included a detailed communications plan to ensure that local pilots were aware of the UAS project and could work with the UAS team to deconflict flights

Interim Flight Clearance (IFC): The NSWCD applied for and received an IFC from the Navy to authorize the flights. The IFC served as an airworthiness document for the ScanEagle® UAS for the FAA COA. The IFC also included specifics regarding operational requirements for the system and the hand-off to the *Fairweather*.

Marine Mammal Protection Act Research Permits: The research was authorized under Marine Mammal Protection Act permit 14245-03, as amended and issued to NMML by the NOAA Fisheries Office of Protected Resources. The research was also authorized under Marine

Mammal Protection Act permit 212570-1, as amended by the U.S. Fish and Wildlife Service to cover the UAS activities.

North Slope Borough Planning and Community Services Department Land Use Permit: Use of the area north of Barrow was authorized under North Slope Borough permits 16-013 and 16-078. The permit had to be amended to accommodate shifts in the physical location of the field site, to extend the date of the project until mid-September, and to accommodate short-term restrictions of traffic near the field site to create a safety zone during launches and retrievals of the UAV.

Memorandum of Agreement (MOA) between NOAA Fisheries and Shell: NOAA Fisheries and Shell signed a MOA on August 3, 2015 that committed the company to install a camera system in the Turbo Commander and provide images for use in this study. The MOA also specified sharing of images and allowed for use of a proprietary system for analyzing the images. Shell informed NMML staff in September that they would no longer be party to the MOA due to the company's plans to abandon further work in the U.S. Arctic. A portion of the images they had committed to provide were sent to NMML in October; the remaining images were delivered to NMML in November.

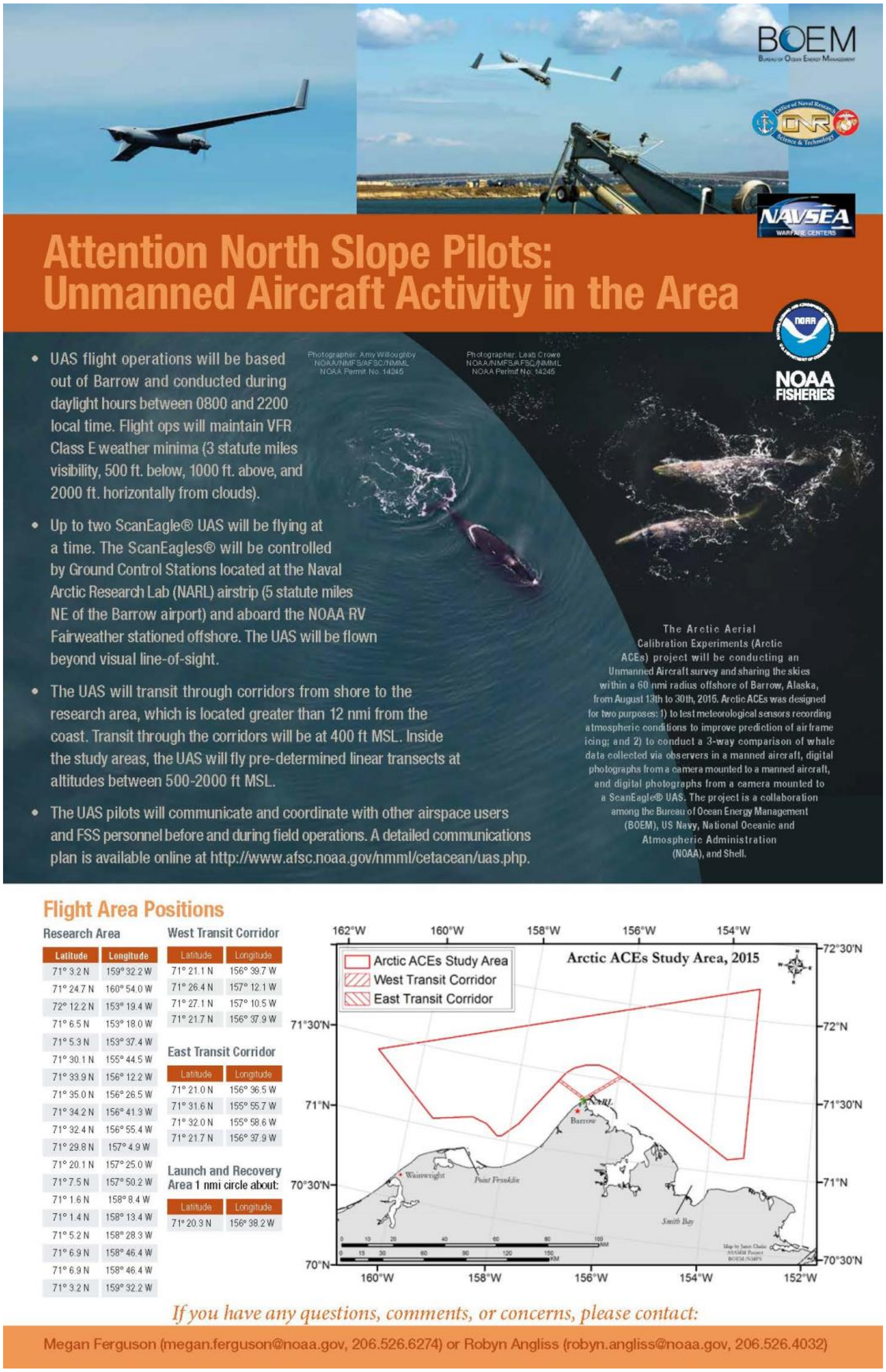
Outreach

Outreach served two key functions: 1) mitigating potential risks to other airspace users due to flying the UAS beyond visual line-of-sight; and 2) integrating the field operations into a remote Alaskan village.

Outreach to and communication with pilots who might be conducting flights in the area were critical components of the strategy to mitigate potential risks of operating the UAS beyond visual line-of-sight. Meetings or calls were held with the Shell pilots actively conducting flights between Barrow and their offshore operations, the commercial passenger airline company Ravn, the Alaska Air Carriers' Association, Barrow Flight Services Station, Alaska Flight Services, and the U.S. Coast Guard. Daily conference calls were conducted on a publically-accessible phone number every day at 0700 hrs (local) so local pilots for both manned and UAS operations could exchange information on their flight plans for the day.

A poster (Figure 11) was developed and electonically circulated to approximately 45 individuals, including local pilots, biologists in agencies or companies who commonly conduct work offshore over the Beaufort and Chukchi seas, and other interested parties. Forty copies of the flyer were posted in Barrow and Deadhorse to alert locals about the project, and it was posted to the FAA-Alaska Public Notices website. Letters and flyers were sent to big game hunting guides permitted to operate on the North Slope who might base somewhere other than Barrow, but could be flying at low altitudes along the coast.

Community outreach included mention of the project on a flyer that was sent to ~300 Alaska Native coastal tribal organizations, villages, and corporations approximately 6 months before the project began (the flyer is available at: http://www.afsc.noaa.gov/nmml/survey_map_2015.htm). A public service announcment was broadcast on Alaska Public Radio in Barrow for a few days starting on 18 August as the team was setting up at the NARL field site. We consulted with the NSBDWM for guidance regarding which Alaska Native community members and organizations we should meet with to provide focused information about the specifics of the project. Meetings or calls were held with the Wainwright Trilateral Council, various individuals in the North Slope Borough Department of Wildlife Management, North Slope Borough Planning and Community Services Department, Inupiat Community of the Arctic Slope, Native Village of Barrow, Ukpeagvik-Inupiat Corporation, North Slope Borough Search and Rescue, Barrow Volunteer Search and Rescue, and the Barrow Department of Public Safety. The team welcomed visitors at the field site, and was able to give impromptu summaries of the project objectives and describe the equipment and procedures.



Attention North Slope Pilots: Unmanned Aircraft Activity in the Area

- UAS flight operations will be based out of Barrow and conducted during daylight hours between 0800 and 2200 local time. Flight ops will maintain VFR Class E weather minima (3 statute miles visibility, 500 ft. below, 1000 ft. above, and 2000 ft. horizontally from clouds).
- Up to two ScanEagle® UAS will be flying at a time. The ScanEagles® will be controlled by Ground Control Stations located at the Naval Arctic Research Lab (NARL) airstrip (5 statute miles NE of the Barrow airport) and aboard the NOAA RV Fairweather stationed offshore. The UAS will be flown beyond visual line-of-sight.
- The UAS will transit through corridors from shore to the research area, which is located greater than 12 nmi from the coast. Transit through the corridors will be at 400 ft MSL. Inside the study areas, the UAS will fly pre-determined linear transects at altitudes between 500-2000 ft MSL.
- The UAS pilots will communicate and coordinate with other airspace users and FSS personnel before and during field operations. A detailed communications plan is available online at http://www.afsc.noaa.gov/nmml/cetacean/uas.php.

The Arctic Aerial Calibration Experiments (Arctic ACEs) project will be conducting an Unmanned Aircraft survey and sharing the skies within a 60 nmi radius offshore of Barrow, Alaska, from August 13th to 30th, 2015. Arctic ACEs was designed for two purposes: 1) to test meteorological sensors recording atmospheric conditions to improve prediction of air frame icing; and 2) to conduct a 3-way comparison of whale data collected via observers in a manned aircraft, digital photographs from a camera mounted to a manned aircraft, and digital photographs from a camera mounted to a ScanEagle® UAS. The project is a collaboration among the Bureau of Ocean Energy Management (BOEM), US Navy, National Oceanic and Atmospheric Administration (NOAA), and Shell.

Flight Area Positions

Research Area

Latitude	Longitude
71° 3.2 N	159° 32.2 W
71° 24.7 N	160° 54.0 W
72° 12.2 N	153° 19.4 W
71° 6.5 N	153° 18.0 W
71° 5.3 N	153° 37.4 W
71° 30.1 N	155° 44.5 W
71° 33.9 N	156° 12.2 W
71° 35.0 N	156° 26.5 W
71° 34.2 N	156° 41.3 W
71° 32.4 N	156° 55.4 W
71° 29.8 N	157° 4.9 W
71° 20.1 N	157° 25.0 W
71° 7.5 N	157° 50.2 W
71° 1.6 N	158° 8.4 W
71° 1.4 N	158° 13.4 W
71° 5.2 N	158° 28.3 W
71° 6.9 N	158° 46.4 W
71° 6.9 N	158° 46.4 W
71° 3.2 N	159° 32.2 W

West Transit Corridor

Latitude	Longitude
71° 21.1 N	156° 39.7 W
71° 26.4 N	157° 12.1 W
71° 27.1 N	157° 10.5 W
71° 21.7 N	156° 37.9 W

East Transit Corridor

Latitude	Longitude
71° 21.0 N	156° 36.5 W
71° 31.6 N	155° 55.7 W
71° 32.0 N	155° 58.6 W
71° 21.7 N	156° 37.9 W

Launch and Recovery Area 1 nmi circle about:

Latitude	Longitude
71° 20.3 N	156° 38.2 W

If you have any questions, comments, or concerns, please contact:

Megan Ferguson (megan.ferguson@noaa.gov, 206.526.6274) or Robyn Angliss (robyn.angliss@noaa.gov, 206.526.4032)

Figure 11. Flyer distributed to alert local community and pilots of the upcoming Arctic ACEs project.

WORK COMPLETED

In FY15, the project team focused exclusively on implementing the field project scheduled for August 2015. The field team met weekly via conference call and developed and tracked the various components of the project, including funds transfer, the COA application, selection of a field site, development of the outreach plan, development of risk management documents and safety plans, integration of a ground control station on the NOAA vessel, and logistics for the 2.5-week field project (Table 2).

Table 2. Summary of milestones completed during preparation for fieldwork.

Milestone	Timing	Responsible Parties
Submit proposals for funding	Dec 2014	NMML
Secure project funding for FY15	Feb 2015	ONR, BOEM, NOAA HQ offices
Commit to ship-based or shore-based project	30 Jan 2015	NMML, OMAO, Dahlgren
Draft CONOPs document presented to the FAA	Feb 2015	NMML, OMAO, Dahlgren
Mission concept review for UASPO	Feb 2015	NMML, Dahlgren
Initiated contract with UIC for onshore logistical support	Apr 2015	NMML, Dahlgren
Outreach to communities, pilots	Feb-Aug 2015	NMML, NSB
Site visit of Barrow and Wainwright; final decision on location of shore-based operations	Mar 2015	NMML, Dahlgren, NSB
Initial meeting with FAA to discuss CONOPs	19 Feb 2015	OMAO, Dahlgren
Submit COA to FAA informally via Navy POC	1 May 2015	Dahlgren
Go/No-go decision based on budget targets	5 May 2015	NMML, Dahlgren
Project review for UASPO	8 May 2015	NMML, Dahlgren
Submit COA request to FAA	May 2015	Dahlgren, OMAO
Test camera systems on calibration targets	20-21 Jul 2015	Dahlgren, NMML
Initiate contracts for bear guards	Jul 2015	NMML
Development of an on-site safety plan	Jul 2015	NMML, NSB
Submit cruise plan to OMAO	Jul 2015	NMML
Traffic awareness application contract and testing	Jul-Aug 2015	OMAO, Dahlgren
Go/No-go decision based on COA/airspace availability	Late Jul 2015	NMML
COA received	3 Aug 2015	Dahlgren, OMAO
Mission readiness review for UASPO	10 Aug 2015	NMML, Dahlgren
IFC received	11 Aug 2015	Dahlgren
UAS gear arrives in Barrow	19 Aug 2015	Dahlgren
Frequency approval received from the FCC	20 Aug 2015	PEMDAS
Field operations	19 Aug – 7 Sept 2015	NMML, Dahlgren, OMAO

The Dahlgren team conducted 5 flights of the ScanEagle® during the study (Table 3; Figure 13). Flights ranged from 1.6 to 6 hours in duration, and 24,590 images were collected during the flights. Immediately after each launch, the UAV circled the launch/recovery site and overflew the calibration target. The UAV transited to the offshore study area using either the east or west

corridor defined in the COA, depending on the best available information about the weather in the area. Once in the offshore study area, the UAV climbed to 1,000 ft MSL and began flying transects.

The ASAMM aerial survey team conducted flights on 7 days during the project (Table 3; Figure 13). Three of these flights (8/31, 9/1, and 9/2) will provide comparative data with the UAS flight on that day; 41,482 vertical images were collected during those flights. One additional flight was conducted during the study period but in an area farther south that had weather more conducive for cetacean observations, and one flight was conducted the day after the last UAS flight.

The local weather was highly variable, both spatially and temporally. The flying weather was typically worse in the morning and improved in the afternoon. On days when flights were possible, the weather within the study area was variable, and there were often patches of squalls or low clouds offshore that were not apparent from the shore. The Dahlgren team kept the UAV clear of clouds and attempted to remain clear of precipitation. The team managed the UAV's interaction with the weather by monitoring the onboard video camera and the temperature/humidity data provided by the PEMDAS ASAPS sensor. The UAV frequently encountered theoretical carburator icing conditions during flights; the team mitigated the potential for carb icing by operating the UAV at a high RPM to keep the engine warm. The appendix provides detailed weather observations from the Barrow weather station during the project; conditions where flights were possible are highlighted in green.

The shore-based UAS team successfully handed off control of the UAS to the ship-based team during the first flight on 26 August. The hand-off to the ship allowed for the distant transects of the study area to be surveyed.

The project design relied on the expectation that two UAS could be flown simultaneously to achieve the calculated number of hours needed for a robust comparison between survey platforms. Unfortunately, the team did not have the opportunity to fly two UAS simultaneously. We elected to not attempt dual flights early in the season until the manned and UAS teams had some practice conducting coordinated flights in close proximity. Later in the season, technical issues and weather restrictions with the UAS precluded dual flights.

Table 3. Summary of hours flown and number of images collected during each flight of the UAS and the manned aircraft, and the utility of each flight to a 3-way or 2-way comparison of technologies.

	UAS flight		**Manned flight**		**Comparison**		
Date	**Flight Hours**	**# of Images**	**Flight Hours**	**# of Images**	**UAV images ↔ observers ↔ manned survey images**	**Observers ↔ manned survey images**	**Comments**
26 Aug	3.7	3,407	3.2	6,341		X	Successful hand-off of UAS from shore-based to ship-based team. Manned aerial survey team did not fly the ACEs pattern.
29 Aug	-	-	3.2	6,100		X	
30 Aug	-	-	3.0	5.940	-	-	Manned flights attempted 2x but aborted due to low ceilings and poor observing conditions.
31 Aug	6	6,818	5.0	9,277	X		Camera mount damaged on retrieval
1 Sept	5.5	6,246	4.8	5,330	X		
2 Sept	5	6,176	4.5	8,494	X	X	Only 2 transects were flown by the ASAMM aircraft in the primary survey area due to poor conditions early in the day
6 Sept	1.6	1,952	-	-			Manned aircraft conducted reconnaissance flight to assess whether UAV flights were likely to be productive; retrieval of the UAS broke the boom on the Skyhook®
7 Sept	-	-	6.2	11,624		X	UAS team returned to Dahlgren & Seattle; manned survey team completed all transects in the study area.
Total	21.8	24,599	29.9	53,106			

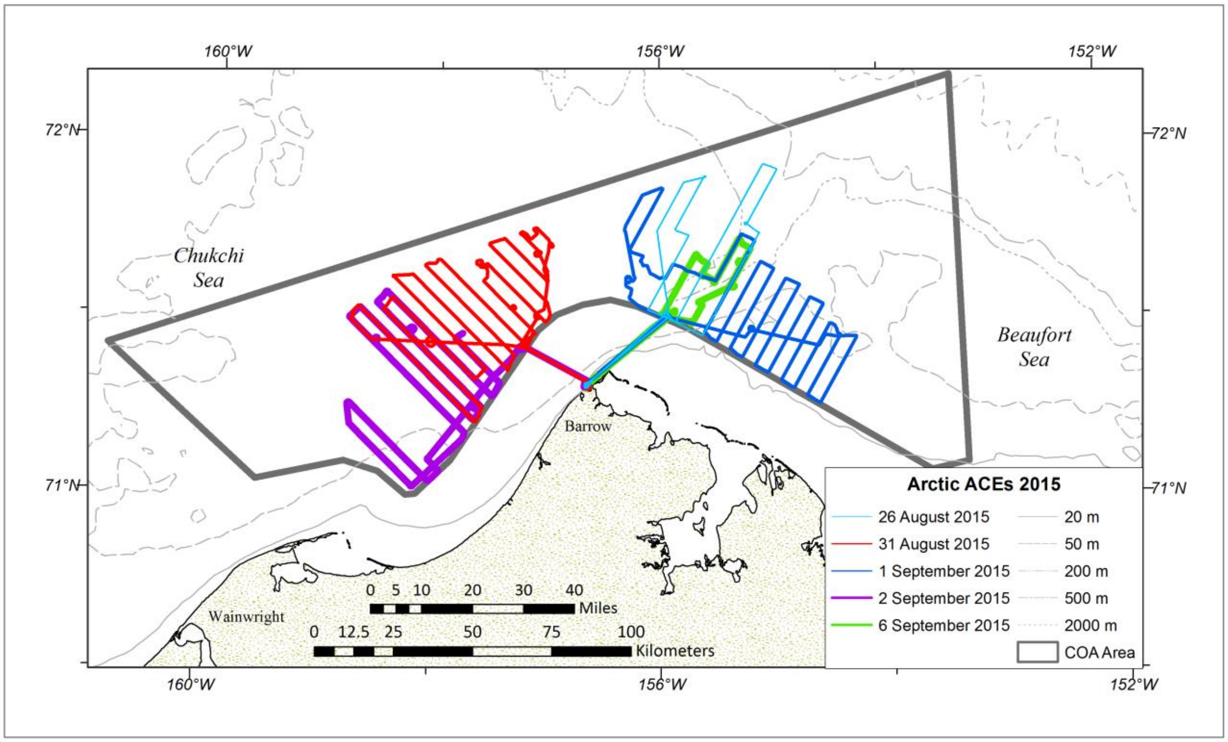


Figure 12. Flights of the UAV during the ACEs project.

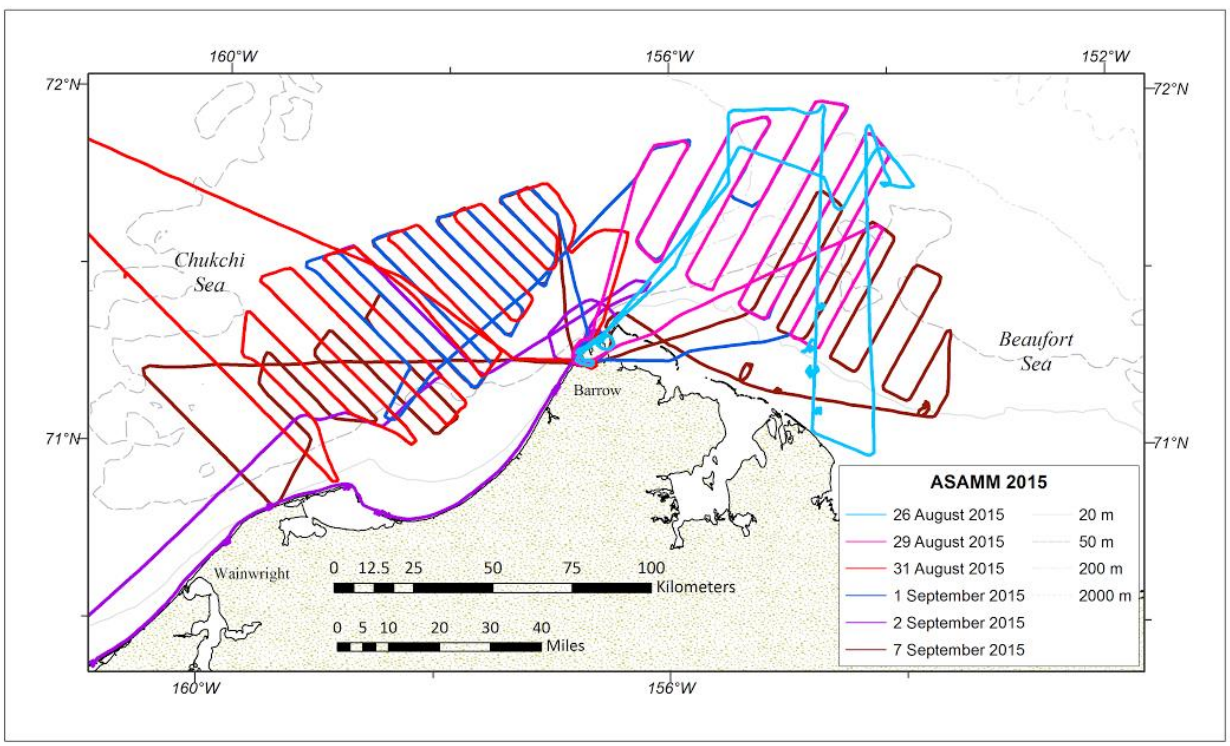


Figure 13. Flights of the ASAMM aircraft during the ACEs project.

RESULTS

Successful implemention of a multi-week UAS project in the Alaskan Arctic

Despite great interest in using UAS in the Arctic, only a handful of projects have successfully used UAS to conduct research. The use of UAS in the Arctic remains in its infancy and the learning curve is still relatively steep. This project successfully conduted 5 flights totalling 21.8 hours over a 17-day period out of Barrow, Alaska. The following detailed list of successes and recommendations is provided to guide future UAS projects, particularly those that are directed at marine mammals or that occur in the Arctic.

Attaining required permissions and authorizations needed for a major UAS project in U.S. National Airspace

<u>Successes</u>

The team successfully applied for and received the following permissions and authorizations:

- FAA Certificate of Authorization (COA) for beyond visual line-of-sight flights
- Navy Interim Flight Clearance
- Amendment to a research permit issued under the Marine Mammal Protection Act addressing NOAA Fisheries-regulated marine mammal species
- Amendment to a research permit issued under the Marine Mammal Protection Act addressing USFWS-regulated marine mammal species
- Land use permit (with amendments) from the North Slope Borough

<u>Recommendations</u>

FAA COAs for future Arctic projects should be as flexible as possible. Pay attention specifically to weather and altitude limitations and the impact they will have on the operations. COAs should also encompass a broad range of dates to accommodate project delays due to technical or logistical problems. While these issues did not significantly impact ability to fly, they could impact future projects.

Use of a shore-based location for the primary ground control station

<u>Successes</u>

The team established a shore-based location for the primary ground control station. Overall, the *location of the shore-based "camp" north of Barrow worked well*. The area was open, and while there were some obstacles nearby (two old hangars, a few tall posts), the UAV could be launched and retrieved from multiple directions. The Arctic Oven tents (3 x 6 m) used to house the ground control stations and provide a place for storage and maintenance of the UAS were minimally adequate. On-site logistics support provided by a local contractor was outstanding. Lodging, food, and hardware supplies were located a short drive away in Barrow. Although

NAVAIR required funds to approve an IFC for the COA for a land-based project; the cost of getting an IFC from NAVAIR for a ship-based project would have been substantially more expensive and time consuming due to the need for a custom install on the vessel available for the project.

Recommendations for the next project

A larger, hard-sided, temperature controlled workspace is preferred for housing the ground control stations and UAV equipment. The small working area inside the tents made movement of people and equipment in and out of the tents more challenging, and meant that it was more difficult for the air boss, pilots and principal investigators to see all equipment at the same time. Further, the labor needed to troubleshoot various issues caused by weather was considerable. Equipment was frequently tested and found fully functional in the evening, yet during flight preparations the next morning, new technical issues would be found and have to be fixed. If a temperature controlled area were sufficiently large to allow the ScanEagles® to be placed indoors with their wings on, it would shorten the time to launch from approximately 2 hours to 45 minutes after arriving at the site.

Better knowledge of potential partners located in the Barrow area might have resulted in being able to site the equipment inside a hard-sided structure. For instance, the Point Barrow DEW line site has lodging, kitchens and workspaces that might have been available to DOD partners. NOAA and Navy staff had tried to contact DEW line staff directly and were unsuccessful via phone and email, but Navy to Air Force communications could have resulted in a different outcome.

The team was advised early in the project that polar bears would not pose a significant risk to staff at the field site, and was then counseled later that steps to ensure *polar bear safety* should be implemented at the field site. Although the bear risk was low, it was not zero; a bear safety plan was developed, distributed, and briefed to the field team. NOAA staff took firearm safety training and brought a shotgun to the field site. Bear guards were hired to stand watch during each flight, or on days when bears were sighted in the vicinity. Three bear sightings occurred near the field site during the field study, which reinforced the need for vigilance. In addition, upon arrival in Barrow, the team heard from the local police department and from other local residents that *night security* would be needed to ensure that key supplies were not stolen or damaged. A contract for night security was established for the first part of the field season; Dahlgren brought an additional team member to Barrow to perform nighttime security for the last week of the field season.

Use of a shore-based site as the location for the primary GCS, launch, and retrieval of the UAS meant that the ScanEagle® system had to be transported to Barrow. This is a significant task due to the considerable size and weight of the launch and recovery equipment, and a C130 was needed to transport the gear. Because the Navy was a partner on this project, transport via Navy C130 was provided free of charge to the project. However, the Navy C130 flight was delayed for 2 weeks, which shifted the end of the field season into September and caused an avalanche of changes in staffing, personnel flight logistics, lodging, et cetera. Chartering a commercial C130 flight from the east coast and return would have cost approximately $500K; chartering a

commercial flight from Fairbanks would have cost approximately $80K. *If a shore-based operation is preferred, future projects that require a fixed-wing UAV would benefit from using a UAV that could launch/land on a runway, eliminating the need for bulky launch and recovery systems*.

Beyond visual line-of-sight flights of the ScanEagle® UAV

Successes

The FAA authorized a beyond visual line-of-sight COA contingent on the use of a rigorous communications plan and using an air traffic awareness tool as a means for sense and avoid. The ScanEagle® UAV has a Mode C transponder that can be detected by airborne TCAS and with ground based air traffic radar. Through an air traffic awareness tool, the air boss was able to see the ScanEagle® UAV and other air traffic in the survey area. The air traffic awareness tool was also useful for monitoring offshore air traffic, particularly the ASAMM aircraft and Shell pilots transiting to Shell's offshore drilling area, both of which were flying at approximately the same altitude. The receipt of a COA for these flights was a notable success, as few COAs for beyond visual line-of-sight flights have been issued by the FAA.

The Dahlgren team successfully *transferred control of the UAS to a vessel* located offshore on the first flight. This allowed distant transects to be surveyed that were beyond the reach of the shore-based GCS.

At no time did the team stand down due to predicted carburetor icing conditions prior to flight. Potential in-flight carburetor icing conditions were managed by running the engines at higher RPM and faster speeds to keep the engine warm. Additionally, the PIC recorded the commanded throttle and respective RPM reading every 15 to 30 minutes to ensure that the engine was not exhibiting degraded performance. The use of fuel-injected engines would not have resulted in increased flight time during this project, but they are recommended as a good solution for the Arctic because of the high potential for carburetor icing issues.

A *detailed communications protocol* was developed so local airspace users – including pilots of both manned and unmanned systems – would be aware of activities in the area each day. The protocol included extensive outreach to pilots, including phone calls and meetings with local pilots working for Ravn and Shell, notices posted around Barrow and emailed directly to pilots and state/federal/local agencies who might employ pilots in the course of their work. During the field season, there were daily simultaneous operations (SIMOPS) calls.

The availability of weather information at the field site – specifically *short-term, high resolution, local information on precipitation* – facilitated UAS flights because it informed the pilots of local environmental conditions within at the field site in lieu of at the airport, which was 5 miles away from the launch and recovery site. The PEMDAS team allowed the pilots to view "NOWcasting" software during the flights, which aided in predicting short-term variation in weather conditions. A similar system developed by the University of Washington can be seen at http://www.atmos.washington.edu/SPU/; the 1-hour forecast product provides information on highly variable weather transiting a small spatial area that would be useful for UAS operations.

In addition, ONR provided a *portable weather station* to the team, which was used late in the field project to assess information on ceiling altitude at the field site. Due to local variability, the ceiling at the field site was often hundreds of feet higher or lower than the ceiling at the airport where the official observations were obtained; having a weather station at the field site enabled the team to measure minimum launch criteria more accurately and frequently.

Recommendations

Develop a better understanding of when carburetor icing occurs in ScanEagle® UAVs. ScanEagles® are very capable platforms but the lack of platform specific information on the conditions under which carburetor icing may be a problem will mean that pilots will tend to be unnecessarily conservative about flights in conditions that the equipment manual might call "marginal". Temperature and humidity data from the ASAPS sensor will be more useful to the UAV operators if more is known about the relationship between the environmental data and the probability of icing on the ScanEagle®. Laboratory tests to evaluate carburetor icing of ScanEagles® would be helpful.

There are a number of features that could be added to a UAV to improve its capability to fly in an arctic environment. A UAS that could be flown in occasional icing conditions and be able to go through clouds could access more areas where the weather is sufficient for marine mammal surveys. Platform updates such as iridium feeds, and modifications to handle icing such as heated pitot tubes, wing boots, and heated propellers would be helpful. For this project, weatherproofing would have been most helpful on the ground, because the team had to work on the UAS in light mist as they waited for local squalls to pass the study area, and it was clear that long-term storage in a cold, damp environment damaged the equipment over time.

Ship-based UAS operations

Requests for vessel time within NOAA have to be made approximately 1.5 years in advance of when the ship is needed for a project. Early advice from ScanEagle® experts suggested that the ScanEagle® could be integrated on the NOAA Ship *Rainier*, the sister ship of the *Fairweather*. The PIs requested time on the *Fairweather* for 2015 and were allocated 21 days at sea in August and September (9 days of transit, 12 days on station). Further investigation confirmed that that a standard integration on the *Fairweather* was not possible unless much of the ship's superstructure was removed from the back deck, which was not deemed feasible for the project. Custom integration would have required significant time and funds, and would require multiple test flights before the Navy leadership would clear the installation for a project. Because of the cost and potential risk to the project (if Navy leadership did not clear a custom installation, the August 2015 field season might be canceled), the team shifted to shore-based operations, with the intent of handing off to a single ship-board ground control station so the full study area could be accessed. In addition, the vessel would be responsible for finding and retrieving a UAV that had an unscheduled water landing, and would provide real-time weather observations at sea. When not being used by the UAS project, the vessel would conduct hydrographic operations to make the best use of the ship's time in the area.

<u>Successes</u>

The team successfully transferred control of the UAV from the shore-based station to the team on *Fairweather* during the first flight of the project. This was the first time the Dahlgren team had accomplished a hand-off from a land based system to a ship based system and the procedure went well.

<u>Recommendations</u>

NOAA should evaluate ships in the NOAA fleet that are likely to be asked to carry UAS to ascertain in advance whether and how UAS integration could occur. This review should include an assessment of deck space needed for launch/recovery, space for the GCS, and space for storage and maintenance of UAS equipment. This type of information should be made available to researchers in advance of a request for vessel time.

The team felt strongly that *future beyond visual line-of-sight arctic maritime operations should be based off a vessel* in lieu of from a shore-based station. Basing off a vessel was considered the single operational change that would have directly and significantly improved the chances of getting the flight hours needed for the project. Often, weather conditions in Barrow were sufficiently poor to prevent launch (low ceilings, fog, or winds) but based on weather reports from the ship there were offshore areas that could have been accessed if the UAV could have been launched from a vessel. Advantages to basing off a ship for this project included:

- Ability to move to areas of good weather within the study area for launch and recovery;
- Equipment would be in a climate-controlled area;
- Long-range flights could require an iridium link; using a mobile ground control station on a ship allows for additional range;
- No need to transport UAS equipment to a shore-based site;
- No need for security or bear protection contracts.

If the project were conducted from a ship, more care would be needed to set up the ScanEagle® UAV so it could be easily transported around the vessel. Because the project was land-based, Dahlgren installed the digital camera payload in a second payload bay that was less complex from an engineering perspective, but added length to the ScanEagle® which would have made it more challenging to maneuver around a vessel.

Payload and equipment

<u>Successes</u>

Overall, the payloads integrated into the UAS worked well: images were successfully collected and downloaded at the end of each flight, the video camera system was useful for in-flight situational awareness, and the ASAPS sensor provided consistent data to the PEMDAS ground station.

The following five payloads were flown on the ScanEagle®:

1. Nikon D810 camera (Figure 14): Pictures were collected to examine cetacean distribution and estimate density.
2. Atmospheric Sensing and Prediction System (ASAPS) Meteorological Sensor (14), developed by PEMDAS, Inc: Meteorological data were sent to the UAS ground station so the UAS operators could analyze current meteorological conditions. The sensor was used to analyze current weather conditions to determine the risk of carburetor icing.
3. EO board camera (14): The EO board camera provided the UAS operator with situational awareness during flight.
4. GPS pinger (15): The GPS pinger was intended to aid in recovery of the UAS in the event of a controlled water landing. The GPS pinger also allowed for GPS metadata to be included with the images taken with the D810 camera.
5. Camera trigger (15): The camera trigger was intended to allow for the D810 camera to have pictures taken based on GPS distance instead of using the camera timer.

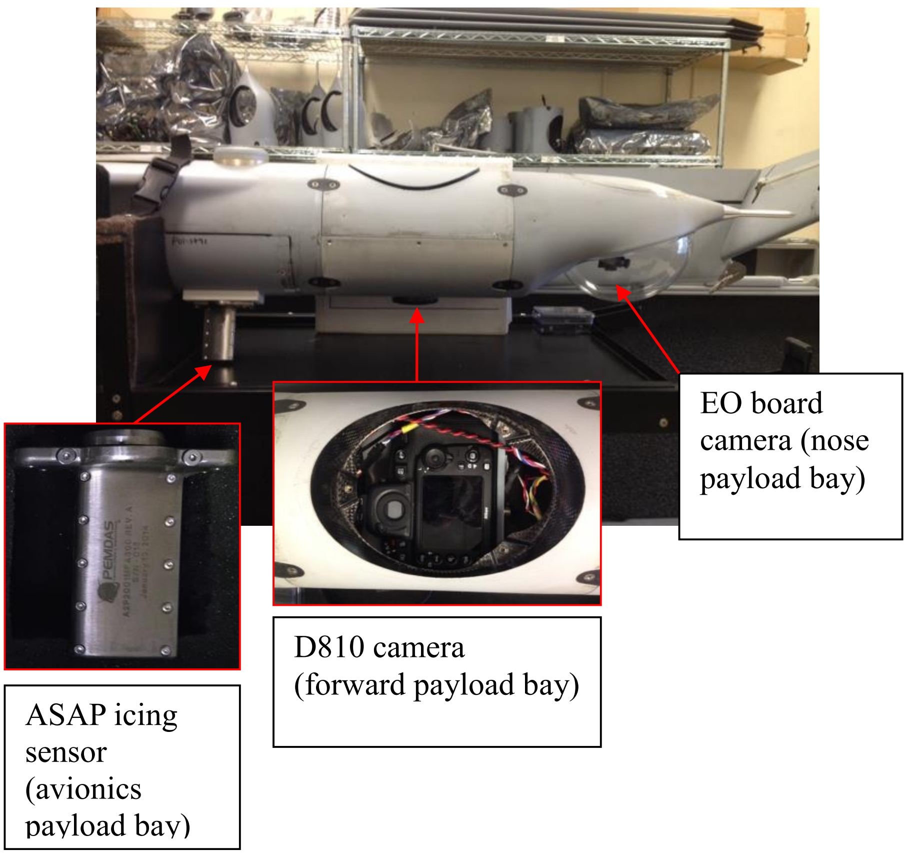


Figure 14. Forward payloads in the ScanEagle®

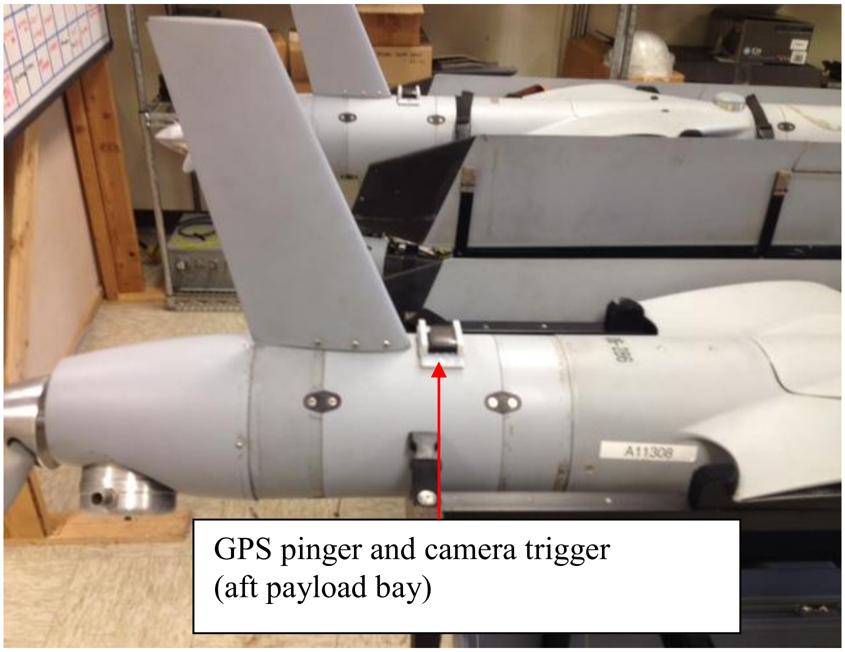


Figure 15. Aft payloads in the ScanEagle®

During the test flights on 20 and 21 July, the camera collected images at 1050 ft MSL with a resolution of 6 cm, which was better than acceptable minimum resolution requirements. However, the light levels at Dahlgren, VA during the test flights were very high, with low to no cloud cover. This allowed for images to be taken at a much higher shutter speed and lower ISO than those collected in the Chukchi study area, resulting in higher image quality during test flights. In addition, because the camera mounts used in Barrow were damaged, there may have been additional vibration of the camera systems that could have further impacted image quality.

Recommendations

There were two issues with the camera mounts. The mounts blocked access to the storage card slot in the camera system so that the card could not be removed from the camera. Thus, post-flight data retrieval required removing the camera from the mount, which caused wear and tear on the mount and a time-intensive transfer protocol. *Future payload mounts should be designed to ensure that key payload features can be accessed during the project*. Secondly, two camera mounts cracked upon retrieval in Barrow and had to be re-anchored in the UAS. The damage was likely due to the weight of the UAS upon retrieval and the type of plastic used for the mount. *Further investigation of the type of plastic used for the mounts may help understand whether the plastic used was optimal for the environmental conditions experienced in the Arctic.*

The Nikon camera calibration images from the UAS indicated that the resolution was adequate for large whale detection and species ID, but was poorer (11 cm) than our initial requirements (7 cm). Image resolution was significantly impacted by higher than expected levels of blur. Upon consultation with aerial photography experts, the consensus is that the blur was caused by the camera mounting method and lack of forward motion compensation. There was no vibration dampening material inserted between the camera and the mounting bracket, which ensured that

any UAS vibrations were transferred directly to the camera. After the initial flight, camera adjustments were made that decreased the image blur slightly, but these adjustments could not compensate for the lack of dampening material.

In order to avoid carburetor icing, the UAV engines were run at a faster speed and higher RPM than during the test flights at Dahlgren, VA. Higher RPM would likely cause greater vibration on the camera mount; this, coupled with lower light levels and increased precipitation between the camera and the sea surface, likely caused the greatest differences in image quality between test image and in-field image resolution.

Another factor that impacted the payload success was the rigidity and permanence of the mount. Once the camera was attached to the mount via screws and hot glue, it was very difficult to remove without damaging the mount or the camera. When adjustments to the lens focus ring were needed, as is frequently the case during the first few flights of a survey, the ring was virtually impossible to access without removal from the mount.

The Nikon D810 camera and associated lens were quite heavy. The weight of the camera system resulted in having to make changes to other parts of the ScanEagle® to accommodate the space and weight of the camera. To save weight, the gimballed turret was removed; it would have been helpful, although was not critical, for situational awareness to have retained the turret so the video camera could pan while the UAS was transiting in a straight line. The weight of the UAS added complexity to the launch and retrieval requirements: if a full tank of fuel were required, a wind of 10 to 15 knots during launch would have been required to meet the specifications of pressurizing the launcher. Future projects requiring this payload should consider *modifying the camera to include only the critical mechanisms* to make it lighter and easier to integrate.

Due to the location of the ASAPS sensor (protruding from the avionics) and the extended dual bay configuration, the wing had to be disconnected from the fuselage in order for the ScanEagle® to fit in the transport case. Once the wing was reconnected to the fuselage, the ScanEagle® could no longer be dropped into the transport case to allow for the case to close for shipping or on-site storage. In addition, the Arctic Oven tents were too small to allow for the wings to be installed in the tent. A different configuration of the ASAPS sensor would be helpful, and *larger transport cases should be built to accommodate a ScanEagle® with an additional payload bay.*

Technology that automatically broadcasts an aircraft's position and detects other aircraft in the general vicinity (such as ADS-B) *should be installed* on both the UAS and on small aircraft that share airspace. This will improve the safety of flight by ensuring that all aircraft are visible to each other.

Overlapping survey design and historical weather conditions: Setting reasonable expectations

Weather conditions were roughly what was expected by the NOAA Fisheries PIs, although were considerably worse than expected by the Dahlgren team. In general, the weather on a "good flight day" in the Arctic would not have been considered an acceptable flight day in many other places in the U.S. The PIs expectations were that a 17-day project in mid-late August should result in 5-6 days of acceptable survey weather. This was estimated based on a review of the number of days that the ASAMM team surveyed during the previous 30 years. In addition, the Dahlgren team examined multiple years of data on wind, temperature, and dew point to assess whether it was reasonable to assume that flights could be conducted for a certain number of days during August. The Dahlgren team concluded independently that based on recent historical weather data, during 4 of 5 years, the project should overlap with 5-6 good flight days in a 17-day period. Thus, the 5 flight days achieved during the project were within the range of the expectations for the project.

Rain prohibited flights on some days but the probability of rain was not specifically evaluated by either team prior to the field season. However, consideration of rain was inherent in the NOAA review of productive flight days by the manned aircraft in previous seasons, and in Dahlgren's consideration of the temperature-dew point split.

Weather in the study area in August can include an adequate ceiling with occasional rain and snow showers that are small in scale and highly variable. It is more challenging to operate UAS in this type of weather because available weather forecasting products do not have the necessary spatial or temporal resolution. The Dahlgren team expected rain conditions that would prohibit flights in the entire study area; instead, operations typically required "dodging" showers or low fog conditions that were transiting a portion of the study area. The nowcasting system provided by the PEMDAS team was helpful in predicting changes in precipitation and ceiling that aided in-flight planning.

Records of daily weather observations at the Barrow airport coupled with the timing of UAS and manned aircraft flights are provided in the appendix.

<u>Recommendations</u>

The ship-based UAS team noted that if the survey design had targeted a lower flight altitude (e.g., 500 or 800 ft), the UAV would have been able to collect more data for the project. However, there is a tradeoff between altitude and swath width; a lower altitude means a narrower swath width, and more hours of flight time would then be necessary to sample the same area. In addition, decreasing the flight altitude would have further decreased the effective communications range.

Coordinating UAS and manned aerial survey flights

One of the goals of the project was to coordinate manned and UAS flights to provide a comparison of images of whales collected by the two platforms. Comparison would be facilitated by having the flights conducted at the same altitude, and preferably in close temporal and spatial proximity to decrease the chance that whale distribution and density would change in the intervening period between sampling.

Successes

In order to ensure safety during the flights, there were both technological and procedural methods for ensuring spatial separation in flight. Written procedural methods were developed in advance of the field season by consensus by the UAS and Clearwater pilots and leads for the two teams. Technological methods included the installation of a transponder in the UAS so nearby aircraft with the Traffic Alert and Collision Avoidance System (TCAS) would be alerted of a possible collision threat, and an traffic awareness application, which allowed the UAS team to monitor aircraft in the vicinity.

Recommendations

During the coordinated flights on 8/26, there were deviations from the written protocols. After this flight, the team leads met, revised the protocols and tested the communications on the ground. On 8/31 there was a successful flight and all communications protocols worked well. During coordinated flights on 9/1, there was another deviation from the protocols. There was no imminent risk to human safety as a result of either occurrence; however, it became clear that the measures put in place to mitigate risk prior to the occurrence of a potential safety issue were not adequate. Thus, the leads for the manned and UAS surveys decided to cease simultaneous flights within the same survey area for the remainder of the project. Manned and UAS surveys were still conducted in the same survey areas on the same day, but not at the same time.

The manned and UAS pilots and the team leads for the various teams identified the following steps to reduce risk during a project that plans to conduct coordinated manned and unmanned surveys <u>at the same altitude and in close proximity</u>:

- Start with a simple coordination plan, and add complexity only after communications and operations are well understood and tested in the field.
- Talk through all procedures (regular and emergency) with the entire survey crew before the project starts. Make sure all parties know what mechanisms are in place to mitigate the risk to people in the coordinating aircraft. Provide the manned survey crew with site visits to the UAS operation location to become familiar with the GCS and traffic awareness capabilities prior to the start of UAS operations. This would allow the manned survey crew to become familiarized with the UAS platform.
- Provide all safety documentation, process documentation, and airspace authorizations to the leads for all teams. Each lead should know the safety requirements, COA restrictions, and any other requirements or restrictions for flights.

- If deconfliction is based on distance between aircraft, ensure that both teams can quickly and accurately measure the required distance using the technology they have available.
- Problems appeared to occur primarily when either the manned or unmanned aircraft changed plans during coordinated flights. It is critical to have a way to communicate deviations from the plan while in the air. VHF communication are sometimes a highly reliable option for communication between pilots in the air and on the ground, although it was not reliable for this project due to restricted VHF range at the shore field site. For UAS and manned aerial flights working in close proximity, good radio communications are likely the surest method of ensuring separation between UAS and manned aircraft flying in close proximity.
- During the development of deconfliction protocols and daily flight planning, talk through potential flight plans with a graphical display of the flight area. Identify any unintentional, potential points of intersection of the project aircraft. For example, for this survey, it would have been less complicated to position the entrance of transit corridors at the ends of the study area to facilitate spatial separation among survey aircraft.
- Everyone should be equally familiar with the NOTAMs issued in the vicinity of the project, particularly those NOTAMs about the project. These may be filed for either the nearshore areas, offshore areas, or both.
- Project team leads should ensure that flight services accurately enters and understands the requested NOTAMS.
- Sense and avoid technology or other onboard air traffic awareness technology (such as ADS-B and TCAS) greatly enhance situational awareness for both manned and unmanned flight crews. Continued development of technological solutions for UAS situational awareness should be a high priority for regions where manned and unmanned aircraft share airspace. A technological solution for situational awareness should be required if manned and unmanned aircraft are likely to be sharing airspace close in time, location, and altitude.
- NOAA and the Navy should develop a joint letter to the FAA asking that the NOTAMs be made available to pilots in a more user-friendly, graphical way.
- Avoid pre-flight rush and urgency to minimize the potential for error.
- Hold post-flight debriefs with all team leads.

Integrating a UAS project into an Alaskan coastal village

<u>Successes</u>

Because this project had a significant shore-side footprint, the PIs had to navigate a variety of expected and unexpected local concerns about the project. NOAA Fisheries staff took the lead when working with the local agencies, organizations, and individuals, due to their long history conducting research on the North Slope and established professional relationships. The team successfully received an initial land use permit to conduct the field work in the village of Barrow, requested and received modifications to the land use permit as needed. Longstanding professional relationships and routine discussions with North Slope Borough staff helped the

team understand what issues might be of concern to local residents so that potential conflicts could be mitigated well in advance of the field project.

Launching and retrieving the UAV required the creation of a “safety zone” to ensure that the UAV did not overfly people or property. Creating this “safety zone” sometimes required management of local traffic along a public road between Barrow and a popular duck hunting area north of town; this was somewhat controversial early in the field season and required a special meeting with the local planning department to explain the need for short-term traffic management.

Recommendations

Site selection for projects should be as transparent as possible. The team investigated two possible locations for the project: Wainwright and Barrow. Wainwright was initially preferred because of its proximity to an area of particularly high whale density. The team opted for Barrow because of cost: working in Wainwright would have required a chartered C130 to transport gear ($80K+) and a substantial fee for use of a gravel pad outside of town. In addition, there was some question regarding whether runway maintenance might prevent flights for part of the summer and the project could have been asked to vacate the gravel pad if an alternative user offered a higher fee. While working in Barrow instead of Wainwright was the best business decision to ensure a successful project, Wainwright officials were openly disappointed about the decision.

The team held weekly teleconferences to establish the shore-side location in Barrow, and North Slope Borough staff provided photos and measurements of the site to aid in site selection. However, an additional trip by members of the team may have expedited the selection of the specific site. This type of trip was discussed at the time, but could not be arranged due to cost and staff schedules. Maps of the site location were exchanged, but there were various opinions about whether dots on the map represented general or specific locations of equipment.

The use of UAS in populated areas is relatively new and local permitting agencies may not yet have a thorough understanding of a UAS projects’ footprint and operations plans, so may not know the right questions to ask an incoming UAS team. In this case, serious concerns about “road closures” to enable a “safety zone” were raised when the team had a public service announcement read on the local radio station to announce the initiation of the project and possible short-term closures of a public road for up to 15 minutes. When concerns were raised, the team immediately committed to not conducting flights until the issue was resolved. After some discussion, it seemed likely that the UAS operators could use on-site communications to minimize or eliminate having to hold traffic on an important public road; this was communicated to the permitting agency during an in-person meeting and the permitting agency was supportive. Minimum traffic delays occurred (approximately 5 personal vehicles over the course of the field season; each time vehicles were delayed for less than 3 minutes); however, it was still unclear when the project began whether delays of 1 to 2 minutes, or tens of minutes would be necessary. The need to hold traffic and the length of time that traffic would need to be held should have been identified earlier in the planning process so this could be highlighted during earlier discussions with the local permitting agency.

Researchers planning to use UAS should err on the side of providing more information to the permitting agencies so they have a thorough understanding of the operation prior to permitting.

Safety and security at the field site

Successes

Overall, the team felt that the project was both safe and secure. Polar bear guards were hired on days when there was increased polar bear risk and on days that staff were less likely to be watchful of the surrounding area because they were flying the UAS. Night security guards were hired for a portion of the season; the Navy brought their own security personnel to monitor the camp at night when funds ran short. North Slope Borough staff were routinely on polar bear patrol throughout town, attended the daily morning meetings, and called in to report bear sightings in the area.

Recommendations

During the field project, poor weather in Barrow led to a local State of Emergency due to coastal flooding that impacted multiple roads, including the only road leading to the field site. While communication between the UAS team and local Risk Management was maintained, it was not always clear when individuals were at the UAS site. Under a State of Emergency, it would have been helpful to have more frequent and detailed communications between the UAS team and the North Slope Borough so the department responsible for knowing where individuals are located could notify the team of rapidly changing road conditions and closures. In addition, since there was only one road to the UAS field site, the team should have considered contingencies such as road closures due to weather. This did not result in traffic delays or any safety risk during the project, but the implications of having only one road to the field site should have been more fully considered.

In addition, Barrow experienced a water shortage shortly after the State of Emergency occurred. This was communicated to UAS team members but not broadly disseminated. In the future, during a State of Emergency, communication with all team members would be more effective if done in a coordinated manner during the routine 0800 hrs team meetings.

IMPACT/APPLICATIONS

UAS are sometimes marketed as a “transformative” or “disruptive” technology that will dramatically change how agencies do business. This is clearly true in some situations: after a few field seasons of evaluation, NOAA Fisheries is now routinely using APH-22 hexacopter UAS to collect mission-critical information on penguins (Goebel et al., 2015), killer whales (Durban et al., 2015), and Steller sea lions (Sweeney et al., in press).

Over the past 6 years, researchers have been gradually evaluating whether UAS with the capability to fly well beyond visual line-of-sight can be used for collecting information on

marine mammal populations that could be used for estimating density, distribution, and abundance. In 2009, Moreland et al. (2015) conducted a within line-of-sight evaluation of whether a ScanEagle® UAS would provide an effective way to assess ice seal distribution in the Bering Sea pack ice. In 2013, Koski et al. (2015) – evaluated the use of the TD100E and a Nikon D800 camera with a 50 mm Nikon lens & concluded that this system would collect images of bowhead whales adequate for photo-identification of individuals when images are collected at low altitudes. Koski et al. (2013) compared the use of human observers to high definition video and fixed digital imagery to evaluate which system would most likely be helpful for marine mammal surveys when mounted in a UAV. Hodgson et al. (2013) conducted within line-of-sight strip-transect surveys using a ScanEagle® to collect observations of dugongs; Maire et al. (2013) worked with A. Hodgson and initiated attempts to automate the image analysis process to increase the speed of analysis. The goal of this project is to build on previous successes and conduct a 3-way comparison between human observers in a manned aircraft, a camera system in a manned aircraft, and a camera system in a technologically advanced UAS, and evaluate the use of automated imaging processsing to speed image analysis.

At this stage of the project we limit the discussion to what we learned from field operations during summer 2015; discussion of the results of the comparison will be provided in a future project report.

The previous section discusses many project successes and provides detailed recommendations about how we could have better met various operational and technological changes. Its helpful to distinguish between which project components directly contributed to data collection (Table 4), and which operational changes are most likely to directly improve data collection (Table 5).

Table 4. Project components that were critical and directly contributed to successful data collection with the UAS, improved safety, or both.

Project component	Comments
Internet service	Critical for weather forecasting, access to air traffic information
Air traffic awareness application	Greatly improved flight safety because UAS team could detect local air traffic; use required by COA
NOWcasting	Increased ability to predict local weather at a spatial and temporal scale unavailable from NWS forecasts.
ASAPS sensor	Helped pilots know when they were likely approaching a cloud or measureable precipitation. Software designed to detect hypothetical carb icing conditions, not actual carb icing conditions.
Portable weather station	The cloud ceiling at the launch site was often hundreds of feet different from the ceiling at the airport.
Open land area with easy access and low traffic volume	Mitigated risks to the community of UAV flying over land.

Table 5. Recommended changes in flight operations. Critical changes are those that that would have resulted directly in increased data collection; other changes might decrease maintenance workload or improve the comfort of the working environment.

Change in operations	Critical	Not critical	Comments
Base from a ship	X		Basing from a ship would allow the team to move to where the weather is favorable for flights.
Climate-controlled storage of UAS gear	X	X	Climate-controlled facility would have minimized maintenance likely required due to near-freezing temperatures, rain, and high humidity.
Automated aircraft position broadcasting and detection technology	X		Improves safety by improving ability to avoid other air traffic; increases size of survey area.
Dampen camera to reduce vibrations	X		Would improve ground resolution, which would aid in detecting large cetaceans, identifying them to species, estimating group size, and detecting calves.
Weatherproof UAS (IFR capability, heated pitot tubes, wing/prop deicing capability)	X	X	Would have been helpful for pre-flight preparations. May have been helpful for collecting data on some days because the UAS would have been able to better handle highly variable patches of precipitation. However, if there is visible precipitation in all areas, visibility is poor and images are not likely to be useful.
Conduct surveys at a lower altitude	X	X	May not be possible given science goals for this project; as flight altitude decreases, swath width decreases, which may be inefficient.
Specify camera access requirements in advance		X	Camera mount blocked access to data port; workaround was time consuming.
Fuel-injected engine		X	The carb icing chart in the Insitu manual is general, not specific to the ScanEagle®. ScanEagle® platforms were routinely flown in icing conditions during this project with no detected effect on the project. However, if a fuel-injected engine had been used, the team would not have needed to run RPMs high to mitigate for the potential of carb icing, which might have avoided degradation of image quality.
Turret for onboard video system		X	Provides ability to see to the left and right while flying straight – aids cloud avoidance
Improve camera/camera mount		X	The camera was heavy, which required that the UAS take on less fuel. The camera mount was not built using the requested type of plastic, and turned out to be quite brittle. The combination of the heavy system and the type of plastic likely contributed to the breakage of two camera mounts.

<u>Future work</u>

The following provide lists of tasks required to be completed in FY15 and FY16. Identification of a task as “required” indicates that it is a formal deliverable in an interagency agreement or other requirement of a funding agency, or is a necessary precursor to developing a particular deliverable. Identification of a task as “planned” indicates a product that has been discussed by the team and is an expected outcome from this research project.

FY16

- Submit a field report (this document) to document the FY15 field season. (Required)
- Provide a post-field season briefing to the funding agencies. (Required)
- Make a presentation (oral or poster) at the Alaska Marine Science Symposium (AMSS). (Required)
- Review images using manual and automated methods. (Required)
- Initiate analytical comparison of density estimates from the human observers, the camera systems on the aircraft, and the camera system on the UAS. (Required)
- Submit a paper for publication documeting 2015 field operations. (Planned)

FY17

- Complete image review and statistical analysis. (Required)
- Develop draft final report and draft technical summary for BOEM. (Required)
- Submit 1-4 papers for publication documenting the results of the various comparisons between human obsevers, cameras in the aircraft, and the camera in the UAS. (Planned)

FY18

- Present final results at the Alaska Marine Science Symposium. (Required)

TRANSITIONS

The goal of this project is to assess under what situations UAS may be able to collect information on marine mammal density that is roughly comparable to data collected from manned aircraft. If the analysis of data from this projects indicates that UAS surveys may provide reliable infromation on marine mammal density within the desired timeframe, this procedure may be transitioned to limited operations by the Navy and other agencies as soon as FY17. Because none of the data have been analyzed, it is too soon to speculate on whether images collected from UAS can be used to estimate density.

However, a few key observations can be made about UAS operations designed to collect density information about cetaceans.

- This ScanEagle® UAS survey has a large physical footprint and gear had to be transported using a Navy C130, which would have been cost prohibitive if the project had been charged for the expense. In addition, the UAS survey required a team of 5 staff (an air boss, 3 staff who could serve as land-based PICs or mechanics, a dedicated mechanic, and a PIC on the associated vessel) to implement a field season. The manned aerial survey requires 5 staff (2 PICs, 3 marine mammal observers) to cover the same geographical area. Other ScanEagle® surveys have involved a smaller team of 3 (2 PICs

and a mechanic; Moreland et al 2015), when only a single UAS is needed. The physical footprint and personnel needs will have to be considered early in the projects' design.

- The survey design for this project required UAS and manned aerial surveys be conducted at the same altitude and in close proximity in time and space. Communications between pilots of the manned and UAS were challenging and coordinated flights in close proximity in time, space, and altitude were discontinued after 3 flights.
- Data from human observers in manned aircraft can be edited and the number of cetaceans observed can be provided within a few hours of the survey aircraft touching down. Based on experience to date, manual analysis of images for one hour of flight time will take approximately 40 hours to review for cetacean observations. For UAS to be a viable option for assessing density or distribution over broad areas, this must be streamlined considerably.

RELATED PROJECT

PEMDAS provided a real-time carburetor icing diagram (Figure 16; upper right hand side of the screenshot). Changes to the way the ScanEagle® was flown were based on this carburetor icing information. For example, the data reflected that the ScanEagle® was almost always in critical carburetor icing. The decision was made to fly at a higher speed/RPM to decrease the likelihood of ice formation. Due to the high risk, additional monitoring of RPM was implemented.

The PEMDAS NOWcasting (Figure 17) provided valuable real-time environmental information to the UAS operators. Changes to the flight path were made based on the data provided. For example, the UAS operator would track an increase in percent humidity and could choose to descend/ascend or change flight path to decrease the possibility of flight through clouds/icing conditions. Additionally, determination of flying the east or west study area used data from NOWcasting as well as pilot reports.

Figure 16. Screenshot from nowcasting and ASAP sensor. The display shows the ScanEagle® flight path with live display of carburetor icing threat, altitude, temperature, humidity, and dewpoint.

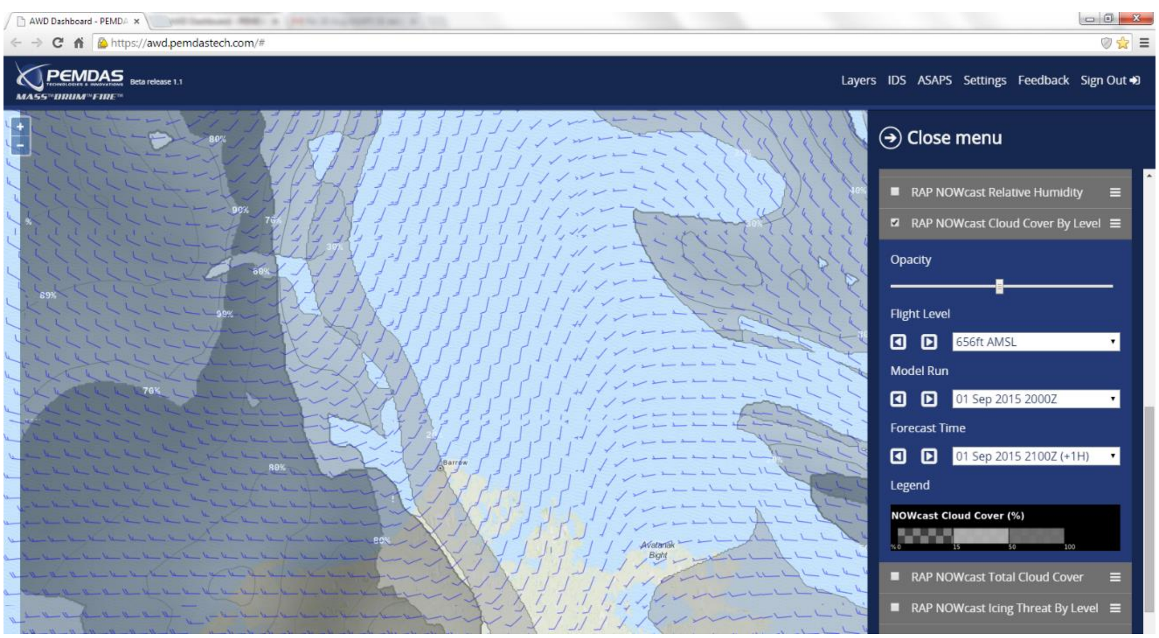


Figure 17. NOWcasting display of forecasted cloud cover at 650 AMSL one hour ahead of current time from 1 Sep 15 flight.

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PUBLICATIONS

None to date.

Appendix. Weather observations made at the Barrow airport from August 14 – September 7 2015. Green shading indicates conditions conducive to conducting surveys with the UAS and the manned aircraft. Erroneous or unavailable weather data are indicated by *. Note that the weather conditions offshore in the study area – or at the shore-based launch/retrieval site – may differ from observations at Barrow.

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
14-Aug	0753	*	0.75		8.3	8.3	*	11	220		
14-Aug	0853	*	1		8.3	8.3	*	11	230		
14-Aug	0953	Overcast layer at 400 ft	6	Mist	8.3	8.3	100	15	230		
14-Aug	1053	Overcast layer at 300 ft	2	Mist	8.9	8.3	96	13	230		
14-Aug	1153	Overcast layer at 300 ft	4	Mist	8.9	8.3	96	13	220		
14-Aug	1253	Overcast layer at 400 ft	9		8.9	8.3	96	14	230		
14-Aug	1353	Overcast layer at 300 ft	4	Mist	8.9	8.3	96	11	230		
14-Aug	1453	Overcast layer at 300 ft	3	Mist	8.9	8.9	100	13	230		
14-Aug	1553	Overcast layer at 300 ft	2	Mist	7.2	7.2	100	9	330		
14-Aug	1653	Broken cloud layer at 400 ft, broken cloud layer at 1000 ft, overcast layer at 1900 ft	10		7.2	6.1	93	8	310		
14-Aug	1753	Broken cloud layer at 600 ft, broken cloud layer at 1600 ft, overcast layer at 2700 ft	10		6.7	6.1	96	10	290		
14-Aug	1853	Broken cloud layer at 500 ft, broken cloud layer at 2800 ft, overcast layer at 4100 ft	10		6.1	5.6	96	10	300		
14-Aug	1953	Broken cloud layer at 500 ft, broken cloud layer at 2800 ft, overcast layer at 4100 ft	10		6.1	5	93	11	300		
14-Aug	2053	Overcast layer at 800 ft	10		5.6	3.9	89	11	300		
14-Aug	2153	Overcast layer at 1400 ft	10		5	2.8	86	10	300		
15-Aug	0753	Overcast layer at 700 ft	10		2.2	1.1	92	8	310		
15-Aug	0853	Overcast layer at 700 ft	10		2.2	0.6	89	3	330		
15-Aug	0953	Overcast layer at 700 ft	10		2.2	1.1	92	0	0		
15-Aug	1053	Overcast layer at 700 ft	10		2.2	0.6	89	5	300		
15-Aug	1153	Overcast layer at 700 ft	10		2.2	0.6	89	6	350		
15-Aug	1253	Overcast layer at 800 ft	10		2.8	0.6	86	8	20		
15-Aug	1353	Overcast layer at 700 ft	10		2.2	0	85	9	20		
15-Aug	1453	Overcast layer at 700 ft	10		2.2	0.6	89	5	80		
15-Aug	1553	Overcast layer at 600 ft	10		2.2	0.6	89	5	60		
15-Aug	1653	Overcast layer at 600 ft	10		2.2	0.6	89	9	70		
15-Aug	1753	Overcast layer at 600 ft	10		2.2	1.1	92	8	50		
15-Aug	1853	Overcast layer at 500 ft	10		2.8	1.1	89	10	80		
15-Aug	1953	Overcast layer at 600 ft	10		2.8	1.7	93	9	80		
15-Aug	2053	Overcast layer at 500 ft	10		2.8	1.1	89	8	60		
15-Aug	2153	Overcast layer at 700 ft	10		2.2	1.1	92	6	90		
16-Aug	0753	Broken cloud layer at 800 ft, overcast layer at 2900 ft	10		3.3	1.7	89	17	70		
16-Aug	0853	Broken cloud layer at 800 ft, overcast layer at 3400 ft	10		3.3	1.7	89	18	70		
16-Aug	0953	Overcast layer at 1100 ft	10		3.9	1.1	82	16	90		
16-Aug	1053	Scattered cloud layer at 1200 ft, overcast layer at 3000 ft	10		3.9	0.6	79	20	80		
16-Aug	1153	Overcast layer at 1100 ft	10		3.9	1.1	82	21	80		
16-Aug	1253	Broken cloud layer at 1000 ft, overcast layer at 2800 ft	10		3.9	1.1	82	18	80		
16-Aug	1353	Broken cloud layer at 900 ft	10		2.8	0.6	86	18	90		
16-Aug	1453	Overcast layer at 800 ft	10		2.8	0.6	86	23	70		
16-Aug	1553	Overcast layer at 700 ft	10		2.8	0.6	86	20	80		
16-Aug	1653	Overcast layer at 900 ft	10		2.8	0	82	22	70		
16-Aug	1753	Overcast layer at 700 ft	10		1.7	0	89	16	80		
16-Aug	1853	Overcast layer at 800 ft	10		1.7	0	89	16	90		
16-Aug	1953	Overcast layer at 800 ft	10		1.1	-0.6	89	18	70		
16-Aug	2053	Overcast layer at 800 ft	10		1.1	-0.6	89	15	90		
16-Aug	2153	Overcast layer at 700 ft	10		0.6	-0.6	92	18	80		

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
17-Aug	0753	Overcast layer at 700 ft	10		1.1	0	92	20	80		
17-Aug	0853	Overcast layer at 700 ft	10		1.7	0	89	21	80		
17-Aug	0953	Broken cloud layer at 800 ft	10		1.7	0	89	20	80		
17-Aug	1053	Broken cloud layer at 900 ft	10		3.3	0.6	82	18	80		
17-Aug	1153	Broken cloud layer at 1000 ft	10		2.8	0.6	86	23	70		
17-Aug	1253	Scattered cloud layer at 1000 ft, broken cloud layer at 10000 ft	10		2.8	0.6	86	21	70		
17-Aug	1353	Scattered cloud layer at 1000 ft, broken cloud layer at 10000 ft	10		3.3	0.6	82	20	60		
17-Aug	1453	Scattered cloud layer at 1000 ft, broken cloud layer at 10000 ft	10		3.9	1.1	82	21	60		
17-Aug	1553	Scattered cloud layer at 1000 ft, broken cloud layer at 12000 ft	10		3.9	1.1	82	22	60		
17-Aug	1653	Scattered cloud layer at 1000 ft, broken cloud layer at 12000 ft	10		3.9	0.6	79	21	70		
17-Aug	1753	Scattered cloud layer at 1000 ft, broken cloud layer at 12000 ft	10		3.3	0.6	82	22	60		
17-Aug	1853	Overcast layer at 11000 ft	10		3.3	0.6	82	18	60		
17-Aug	1953	Broken cloud layer at 9500 ft	10		2.8	0	82	20	70		
17-Aug	2053	Overcast layer at 11000 ft	10		2.8	0.6	86	15	70		
17-Aug	2153	Overcast layer at 11000 ft	10		2.2	0.6	89	16	60		
18-Aug	0753	Few clouds at 1400 ft, scattered cloud layer at 10000 ft	10		1.7	-1.1	82	14	70		
18-Aug	0853	Broken cloud layer at 1500 ft	10		2.2	-1.1	79	15	70		
18-Aug	0953	Overcast layer at 1400 ft	10		1.7	-1.1	82	13	60		
18-Aug	1053	Broken cloud layer at 1300 ft, overcast layer at 2000 ft	10		2.2	-1.1	79	15	50		
18-Aug	1153	Broken cloud layer at 1400 ft, overcast layer at 2000 ft	10		2.2	-1.1	79	15	60		
18-Aug	1253	Broken cloud layer at 1600 ft, overcast layer at 2100 ft	10		2.8	-0.6	79	10	60		
18-Aug	1353	Broken cloud layer at 1500 ft, overcast layer at 2000 ft	8	Light rain	2.2	0	85	16	70		
18-Aug	1453	Broken cloud layer at 1600 ft, overcast layer at 2200 ft	8		2.8	-0.6	79	16	60		
18-Aug	1553	Scattered cloud layer at 1000 ft, broken cloud layer at 1700 ft, overcast layer at 2400 ft	10		2.8	-1.1	76	16	60		
18-Aug	1653	Broken cloud layer at 1500 ft, overcast layer at 2100 ft	5	Light rain, light snow, mist	1.7	-0.6	85	16	60		
18-Aug	1753	Broken cloud layer at 1900 ft, overcast layer at 2400 ft	10		1.7	-1.1	82	14	80		
18-Aug	1853	Few clouds at 1500 ft, broken cloud layer at 2100 ft, broken cloud layer at 11000 ft	10		1.7	-1.7	79	14	70		
18-Aug	1953	Few clouds at 2000 ft, overcast layer at 2700 ft	10		1.7	-1.1	82	11	50		
18-Aug	2053	Broken cloud layer at 1600 ft, broken cloud layer at 2400 ft, overcast layer at 11000 ft	10		1.7	-1.1	82	10	90		
18-Aug	2153	Broken cloud layer at 1600 ft, overcast layer at 2200 ft	10		1.7	-1.1	82	9	90		
19-Aug	0753	Overcast layer at 3200 ft	10		1.1	-1.7	82	5	130	Wait for C130 to arrive	
19-Aug	0853	Overcast layer at 2600 ft	10		1.7	-2.2	76	0	0	Wait for C130 to arrive	
19-Aug	0953	Broken cloud layer at 2000 ft, overcast layer at 3000 ft	10		2.2	-2.2	73	0	0	Wait for C130 to arrive	
19-Aug	1053	Broken cloud layer at 2500 ft	10		2.2	-2.2	73	5	80	Wait for C130 to arrive	
19-Aug	1153	Overcast layer at 2800 ft	10		2.2	-2.2	73	6	100	Wait for C130 to arrive	
19-Aug	1253	Overcast layer at 3000 ft	10		2.8	-3.3	65	0	0	Wait for C130 to arrive	
19-Aug	1353	Overcast layer at 3000 ft	10		2.8	-3.3	65	3	70	Wait for C130 to arrive	

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
19-Aug	1453	Overcast layer at 3000 ft	10		3.3	-2.8	65	6	80	Wait for C130 to arrive	
19-Aug	1553	Overcast layer at 2900 ft	10		2.8	-2.8	67	6	70	Wait for C130 to arrive	
19-Aug	1653	Overcast layer at 2800 ft	10		2.8	-2.8	67	8	90	Wait for C130 to arrive	
19-Aug	1753	Overcast layer at 2900 ft	10		2.8	-3.3	65	9	80	Wait for C130 to arrive	
19-Aug	1853	Overcast layer at 3000 ft	10		2.2	-2.8	70	9	100	Move gear; set up operations	
19-Aug	1953	Overcast layer at 3000 ft	10		2.2	-2.8	70	8	100	Move gear; set up operations	
19-Aug	2053	Broken cloud layer at 3200 ft	10		1.1	-2.8	76	6	100	Move gear; set up operations	
19-Aug	2153	Few clouds at 3300 ft	10		-1.7	-3.9	85	8	110	Move gear; set up operations	
20-Aug	0753	Broken cloud layer at 3200 ft	10		0.6	-1.1	89	9	120	Set up operations	
20-Aug	0853	Scattered cloud layer at 3100 ft, scattered cloud layer at 20000 ft	10		1.7	-2.2	76	8	130	Set up operations	
20-Aug	0953	Scattered cloud layer at 3000 ft, scattered cloud layer at 20000 ft	10		2.2	-3.3	67	7	110	Set up operations	
20-Aug	1053	Scattered cloud layer at 3500 ft, scattered cloud layer at 20000 ft	10		2.8	-2.8	67	11	100	Set up operations	
20-Aug	1153	No clouds below 12000 ft	10		3.3	-3.3	62	10	100	Set up operations	
20-Aug	1253	Scattered cloud layer at 3800 ft, scattered cloud layer at 10000 ft	10		3.3	-3.3	62	11	100	Set up operations	
20-Aug	1353	Scatteed cloud layer at 10000 ft	10		3.3	-2.8	65	10	80	Set up operations	
20-Aug	1453	Few clouds at 2500 ft, overcast layer at 10000 ft	10		3.3	-2.2	67	9	80	Set up operations	
20-Aug	1553	Scattered cloud layer at 2000 ft, broken cloud layer at 9500 ft	10		3.3	-1.7	70	9	100	Set up operations	
20-Aug	1653	Broken cloud layer at 2000 ft	10		3.3	-1.1	73	7	80	Set up operations	
20-Aug	1753	Scattered cloud layer at 2100 ft	10		2.8	-1.1	76	7	70	Set up operations	
20-Aug	1853	Broken cloud layer at 3200 ft	10		2.2	-1.1	79	8	60	Set up operations	
20-Aug	1953	Few clouds at 1400 ft, overcast layer at 3700 ft	10		2.8	-0.6	79	8	90	Set up operations	
20-Aug	2053	*	1		1.7	1.1	*	5	90	Set up operations	
20-Aug	2153	Overcast layer at 800 ft	9	Light rain	1.7	1.1	96	7	100		
21-Aug	0753	Overcast layer at 600 ft	9		1.1	0	92	11	90		
21-Aug	0853	Overcast layer at 600 ft	6	Mist	1.1	0.6	96	11	90		
21-Aug	0953	Broken cloud layer at 600 ft, overcast layer at 1100 ft	10		2.2	1.1	92	14	70		
21-Aug	1053	Overcast layer at 500 ft	9		2.8	1.7	93	14	80		
21-Aug	1153	Overcast layer at 400 ft	3	Mist	3.3	2.2	93	16	80		
21-Aug	1253	Broken cloud layer at 600 ft, overcast layer at 1200 ft	10		3.9	2.8	93	16	90		
21-Aug	1353	Overcast layer at 500 ft	10		3.9	2.2	89	18	80		
21-Aug	1453	Overcast layer at 500 ft	10	Light rain	3.3	2.2	93	17	90		
21-Aug	1553	Broken cloud layer at 500 ft, broken cloud layer at 1900 ft, overcast layer at 2600 ft	10	Light rain	3.3	2.2	93	14	90		
21-Aug	1653	Broken cloud layer at 500 ft, overcast layer at 2000 ft	10	Light rain	3.3	2.2	93	17	90		
21-Aug	1753	Broken cloud layer at 500 ft, overcast layer at 2000 ft	8	Light rain	2.8	2.2	96	16	90		
21-Aug	1853	Overcast layer at 500 ft	9	Light rain	2.8	2.2	96	16	100		
21-Aug	1953	Broken cloud layer at 500 ft, overcast layer at 2800 ft	10	Light rain	2.2	1.7	96	17	100		
21-Aug	2053	Broken cloud layer at 500 ft, overcast layer at 2800 ft	10		2.2	1.7	96	15	100		
21-Aug	2153	Broken cloud layer at 500 ft, overcast layer at 3000 ft	10		1.7	1.1	96	15	100		

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
22-Aug	0753	Broken cloud layer at 500 ft, overcast layer at 3300 ft	10	Light rain	1.7	1.1	96	15	90		
22-Aug	0853	Overcast layer at 500 ft	8	Light rain	2.2	1.1	92	15	90		
22-Aug	0953	Scattered cloud layer at 500 ft, overcast layer at 2300 ft	6	Light rain, mist	2.2	1.7	96	18	80		
22-Aug	1053	Broken cloud layer at 500 ft, broken cloud layer at 2900 ft, overcast layer at 3500 ft	7	Light rain	2.2	1.7	96	16	80		
22-Aug	1153	Broken cloud layer at 600 ft, overcast layer at 1000 ft	5	Light rain, mist	2.2	1.7	96	15	80		
22-Aug	1253	Overcast layer at 700 ft	7	Light rain	2.2	1.7	96	15	80		
22-Aug	1353	Broken cloud layer at 600 ft, overcast layer at 1000 ft	10	Light rain	2.2	1.7	96	16	70		
22-Aug	1453	Overcast layer at 800 ft	10		2.8	1.7	93	14	70		
22-Aug	1553	Overcast layer at 600 ft	10		2.8	2.2	96	14	70		
22-Aug	1653	Overcast layer at 500 ft	10		2.8	1.7	93	14	80		
22-Aug	1753	Overcast layer at 400 ft	10		2.8	2.2	96	15	80		
22-Aug	1853	Overcast layer at 400 ft	10		2.2	1.7	96	11	80		
22-Aug	1953	Overcast layer at 300 ft	8		2.2	1.7	96	10	80		
22-Aug	2053	Overcast layer at 400 ft	10		2.2	1.7	96	11	80		
22-Aug	2153	Overcast layer at 400 ft	10	Light rain	1.7	1.7	100	8	80		
23-Aug	0753	Overcast layer at 400 ft	9		1.7	1.1	96	6	60		
23-Aug	0853	Overcast layer at 600 ft	10		2.2	1.1	92	8	80		
23-Aug	0953	Broken cloud layer at 600 ft, overcast layer at 1000 ft	10		2.2	1.1	92	9	80		
23-Aug	1053	Overcast layer at 600 ft	10		2.8	1.7	93	10	80		
23-Aug	1153	Overcast layer at 500 ft	10		2.8	1.7	93	9	90		
23-Aug	1253	Overcast layer at 600 ft	10		2.8	1.7	93	13	80		
23-Aug	1353	Overcast layer at 500 ft	10		2.8	2.2	96	11	80		
23-Aug	1453	Overcast layer at 400 ft	10		2.8	1.7	93	13	80		
23-Aug	1553	Overcast layer at 500 ft	10		2.8	1.7	93	14	80		
23-Aug	1653	Overcast layer at 400 ft	10		2.2	1.7	96	11	90		
23-Aug	1753	Overcast layer at 600 ft	10		2.2	1.7	96	15	90		
23-Aug	1853	Overcast layer at 400 ft	10		1.7	1.1	96	13	100		
23-Aug	1953	Overcast layer at 400 ft	10		1.7	1.1	96	15	100		
23-Aug	2053	Overcast layer at 300 ft	8		1.1	1.1	100	16	100		
23-Aug	2153	Overcast layer at 300 ft	7		1.1	0.6	96	16	100		
24-Aug	0753	*	0.25		0.6	0.6	*	15	100		
24-Aug	0853	*	0.25		1.1	1.1	*	15	100		
24-Aug	0953	Overcast layer at 300 ft	2.5	Mist	1.1	1.1	100	17	100		
24-Aug	1053	Overcast layer at 300 ft	8		1.7	1.1	96	14	110		
24-Aug	1153	Overcast layer at 500 ft	10		2.2	1.7	96	17	120		
24-Aug	1253	Overcast layer at 500 ft	10		2.8	2.2	96	16	110		
24-Aug	1353	Overcast layer at 500 ft	7		2.8	2.2	96	15	110		
24-Aug	1453	Overcast layer at 300 ft	5	Mist	2.8	2.2	96	17	110		
24-Aug	1553	Overcast layer at 400 ft	10		3.3	2.2	93	16	110		
24-Aug	1653	Overcast layer at 400 ft	10		2.8	2.2	96	18	100		
24-Aug	1753	Overcast layer at 500 ft	10		3.3	2.2	93	18	100		
24-Aug	1853	Overcast layer at 200 ft	5	Mist	2.8	2.2	96	17	100		
24-Aug	1953	Overcast layer at 200 ft	5	Mist	2.2	1.7	96	20	120		

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
24-Aug	2053	*	0.25		1.1	1.1	*	17	100		
24-Aug	2153	*	0.25		1.7	1.1	*	20	100		
25-Aug	0753	Overcast layer at 500 ft	10	Light rain	6.1	6.1	100	14	140		
25-Aug	0853	Broken cloud layer at 4000 ft, overcast layer at 6000 ft	9	Light rain	7.2	7.2	100	11	160		
25-Aug	0953	Broken cloud layer at 4700 ft, overcast layer at 5500 ft	7	Light rain	8.3	8.3	100	13	170		
25-Aug	1053	Overcast layer at 2200 ft	10		8.9	8.3	96	10	160		
25-Aug	1153	Overcast layer at 2200 ft	10		10	8.9	93	10	170		
25-Aug	1253	Overcast layer at 2400 ft	9		10	8.9	93	13	170		
25-Aug	1353	Broken cloud layer at 3700 ft, overcast layer at 4700 ft	4	Light rain, mist	10	9.4	96	10	170		
25-Aug	1453	Overcast layer at 4300 ft	3	Light rain, mist	10	10	100	7	160		
25-Aug	1553	Scattered cloud layer at 1800 ft, overcast layer at 4700 ft	10		10.6	10	96	7	160		
25-Aug	1653	Few clouds at 700 ft, broken cloud layer at 2300 ft, overcast at 3700 ft	5	Mist	11.1	10.6	96	9	180		
25-Aug	1753	*	0.75		8.9	8.9	*	6	270		
25-Aug	1853	Scattered cloud layer at 1900 ft, broken cloud layer at 2500 ft, overcast layer at 3600 ft	2.5	Light rain, mist	10	9.4	96	3	230		
25-Aug	1953	Overcast layer at 3000 ft	5	Light rain, mist	10	10	100	7	190		
25-Aug	2053	Broken cloud layer at 1100 ft, overcast layer at 2100 ft	10		10	9.4	96	13	210		
25-Aug	2153	Few clouds at 1500 ft, broken cloud layer at 2900 ft, overcast layer at 6000 ft	10		9.4	8.9	96	14	220		
26-Aug	0753	Broken cloud layer at 1600 ft, overcast layer at 2200 ft	10		5.6	3.9	89	18	220		
26-Aug	0853	Few clouds at 900 ft, broken cloud layer at 1700 ft	7		5.6	4.4	93	15	230		Start flight 227 (0914)
26-Aug	0953	Scattered cloud layer at 1500 ft, broken cloud layer at 2300 ft, broken cloud layer at 2800 ft	10		6.1	3.3	83	17	230		Flight 227 underway
26-Aug	1053	Few clouds at 1000 ft, broken cloud layer at 1700 ft, broken cloud layer at 2200 ft	6	Mist	5.6	3.9	89	20	240	Start flight 1 (1050)	Flight 227 underway
26-Aug	1153	Few clouds at 1300 ft, broken cloud layer at 2000 ft, broken cloud layer at 2800 ft	10		5.6	3.3	86	18	240	Flight 1 underway	Flight 227 underway
26-Aug	1253	Few clouds at 1600 ft, scattered cloud layer at 2300 ft, broken cloud layer at 3200 ft	10		5.6	3.3	86	17	240	Flight 1 underway	End flight 227 (1228)
26-Aug	1353	Scattered cloud layer at 1000 ft, broken cloud layer at 1400 ft, overcast layer at 2700 ft	2.5	Light rain, mist	5	3.3	89	22	250	Flight 1 underway	
26-Aug	1453	Scattered cloud layer at 1200 ft, broken cloud layer at 1900 ft	10		5.6	3.3	86	22	250	End flight 1 (1445)	
26-Aug	1553	Scattered cloud layer at 1200 ft, scattered cloud layer at 1300 ft, broken cloud layer at 2000 ft	7		4.4	2.8	89	24	260		
26-Aug	1653	Overcast layer at 2100 ft	10		5	1.7	79	21	260		
26-Aug	1753	Few clouds at 1700 ft, broken cloud layer at 2700 ft, broken cloud layer at 3200 ft	10		4.4	1.7	82	23	260		
26-Aug	1853	Scattered cloud layer at 1800 ft, broken cloud layer at 3200 ft	10		4.4	1.1	79	25	260		
26-Aug	1953	Scattered cloud layer at 2000 ft, broken cloud layer at 2600 ft, broken cloud layer at 3300 ft	9		3.9	1.1	82	25	260		

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
26-Aug	2053	Scattered cloud layer at 1900 ft, broken cloud layer at 2700 ft, broken cloud layer at 3200 ft	7		3.3	1.1	86	26	260		
26-Aug	2153	Scattered cloud layer at 2200 ft, broken cloud layer at 2800 ft	9	Light rain	3.3	0	79	25	260		
27-Aug	0753	Broken cloud layer at 1700 ft, broken cloud layer at 2400 ft, overcast layer at 4600 ft	6	Light rain	2.8	0	82	32	280		
27-Aug	0853	Few clouds at 2200 ft, overcast layer at 5000 ft	8		2.8	-0.6	79	31	280		
27-Aug	0953	Few clouds at 1800 ft, scattered cloud layer at 3800 ft, overcast layer at 4900 ft	6	Light snow, mist	2.2	0	85	30	280		
27-Aug	1053	Scattered cloud layer at 1700 ft, scattered cloud layer at 2900 ft, overcast layer at 4600 ft	6	Mist	2.8	0.6	86	33	280		
27-Aug	1153	Few clouds at 1400 ft, broken cloud layer at 1900 ft, overcast layer at 4000 ft	8	Light rain	3.3	-0.6	76	31	280		
27-Aug	1253	Few clouds at 1700 ft, broken cloud layer at 3800 ft, overcast layer at 4600 ft	7	Light snow	3.3	0	79	31	280		
27-Aug	1353	Scattered cloud layer at 1600 ft, broken cloud layer at 2400 ft, overcast layer at 4100 ft	6	Light rain	3.3	0.6	82	33	270		
27-Aug	1453	Few clouds at 1200 ft, scattered cloud layer at 1700 ft, overcast layer at 4200 ft	7	Light rain	2.8	0.6	86	32	280		
27-Aug	1553	Broken cloud layer at 1600 ft, broken cloud layer at 2100 ft, overcast layer at 3700 ft	6	Light rain	3.3	0.6	82	32	270		
27-Aug	1653	Few clouds at 1200 ft, scattered cloud layer at 1900 ft, broken cloud layer at 3500 ft	7	Light rain	2.8	0.6	86	33	270		
27-Aug	1753	Broken cloud layer at 1900 ft, overcast layer at 2900 ft	6	Haze	2.8	0	82	33	270		
27-Aug	1853	Scattered cloud layer at 1900 ft, scattered cloud layer at 2600 ft, overcast layer at 3600 ft	6	Mist	3.3	0	79	29	260		
27-Aug	1953	Broken cloud layer at 2000 ft, broken cloud layer at 3000 ft, overcast layer at 3600 ft	6	Light rain, mist	2.8	0	82	31	260		
27-Aug	2053	Scattered cloud layer at 2400 ft, overcast layer at 3100 ft	7	Mist	2.8	-1.1	76	32	270		
27-Aug	2153	Broken cloud layer at 2800 ft, overcast layer at 3400 ft	7	Mist	2.8	-1.1	76	30	260		
28-Aug	0753	Scattered cloud layer at 1200 ft, broken cloud layer at 2900 ft, overcast layer at 6000 ft	5	Light rain, mist	2.2	0.6	89	23	250		
28-Aug	0853	Scattered cloud layer at 1600 ft, broken cloud layer at 2500 ft, overcast layer at 6500 ft	7	Light rain	2.8	0.6	86	23	240		
28-Aug	0953	Few clouds at 1600 ft, broken cloud layer at 2200 ft, overcast layer at 4800 ft	9	Light rain	2.8	0.6	86	28	250		
28-Aug	1053	Scattered cloud layer at 1600 ft, broken cloud layer at 2100 ft, overcast layer at 3000 ft	9	Light rain	2.8	0	82	22	250		
28-Aug	1153	Scattered cloud layer at 2000 ft, broken cloud layer at 2900 ft, overcast layer at 6000 ft	10		2.8	-1.1	76	21	240		
28-Aug	1253	Scattered cloud layer at 2100 ft, broken cloud layer at 3700 ft, overcast layer at 6000 ft	10		2.8	0	82	23	250		
28-Aug	1353	Few clouds at 1700 ft, broken cloud layer at 2900 ft, overcast cloud layer at 7000 ft	10		2.8	0	82	23	240		
28-Aug	1453	Scattered cloud layer at 2100 ft, broken cloud layer at 3000 ft, overcast layer at 7500 ft	7	Light rain	2.2	0	85	18	250		
28-Aug	1553	Scattered cloud layer at 1800 ft, broken cloud layer at 5000 ft, overcast layer at 6500 ft	10	Light rain	2.8	0	82	17	250		

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
28-Aug	1653	Few clouds at 1200 ft, broken cloud layer at 2800 ft, overcast layer at 5000 ft	5	Light rain, mist	1.7	0.6	92	13	260		
28-Aug	1753	Few clouds at 1000 ft, overcast layer at 1700 ft	3	Light rain, mist	1.1	0	92	15	260		
28-Aug	1853	Scattered cloud layer at 1200 ft, broken cloud layer at 1700 ft, overcast layer at 2900 ft	8	Light rain	1.7	0	89	17	260		
28-Aug	1953	Scattered cloud layer at 1000 ft, broken cloud layer at 1600 ft, overcast layer at 2900 ft	10	Light rain	2.2	0.6	89	16	260		
28-Aug	2053	Scattered cloud layer at 1100 ft, scattered cloud layer at 1600 ft, overcast layer at 3400 ft	7	Light rain	1.7	0.6	92	18	270		
28-Aug	2153	Few clouds at 1200 ft, scattered cloud layer at 1800 ft, overcast layer at 3400 ft	8	Light rain	1.1	0	92	17	270		
29-Aug	0753	Scattered cloud layer at 3500 ft, overcast layer at 4600 ft	5	Light snow, mist	0.6	0	96	7	180		
29-Aug	0853	Few clouds at 600 ft, scattered cloud layer at 1300 ft, overcast layer at 1800 ft	1.25	Light snow, mist	0	0	100	9	190		
29-Aug	0953	Overcast layer at 1200 ft	1.25	Light snow, mist	0	0	100	9	180		
29-Aug	1053	Scattered cloud layer at 1200 ft, overcast layer at 3700 ft	7	Light snow	1.1	0.6	96	9	180		
29-Aug	1153	Broken cloud layer at 500 ft, broken cloud layer at 3700 ft, overcast layer at 4700 ft	10		1.7	1.1	96	10	200		
29-Aug	1253	Broken cloud layer at 600 ft, broken cloud layer at 2900 ft, overcast layer at 3700 ft	10		2.2	1.1	92	9	190		
29-Aug	1353	Few clouds at 900 ft, scattered cloud layer at 4500 ft, overcast layer at 5500 ft	10		2.2	0.6	89	7	200		
29-Aug	1453	Few clouds at 700 ft, broken cloud layer at 5500 ft, overcast layer at 6500 ft	10		1.7	0.6	92	7	180		
29-Aug	1553	Broken cloud layer at 800 ft, broken cloud layer at 1400 ft, overcast layer at 5000 ft	10		2.2	1.1	92	6	180		
29-Aug	1653	Few clouds at 1000 ft, broken cloud layer at 1700 ft, overcast layer at 3800 ft	10		2.2	0.6	89	8	200		Start flight 228 (1714)
29-Aug	1753	Broken cloud layer at 1500 ft, broken cloud layer at 8000 ft	10		2.2	0.6	89	8	170		Flight 228 underway
29-Aug	1853	Scattered cloud layer at 1100 ft, broken cloud layer at 1600 ft, overcast layer at 4700 ft	10		2.2	0.6	89	10	160		Flight 228 underway
29-Aug	1953	Broken cloud layer at 6000 ft, overcast layer at 7000 ft	10		1.7	0.6	92	7	150		Flight 228 underway
29-Aug	2053	Few clouds at 10000 ft	10		0	-0.6	96	5	130		Flight 228 underway
29-Aug	2153	Broken cloud layer at 6500 ft	10		0	-0.6	96	7	110		Flight 228 underway
30-Aug	0753	Broken cloud layer at 800 ft, broken cloud layer at 1000 ft, overcast layer at 2500 ft	10		2.8	1.1	89	13	80		Flight 228 underway
30-Aug	0853	Broken cloud layer at 800 ft, broken cloud layer at 1000 ft, overcast layer at 2500 ft	10		2.8	1.1	89	10	80		End flight 228 (2026)
30-Aug	0953	Broken clould layer at 1300 ft	9		3.9	2.2	89	10	60		
30-Aug	1053	Broken cloud layer at 1500 ft, broken cloud layer at 2800 ft	10		3.9	1.1	82	13	90		Start flight 229a (1117)
30-Aug	1153	Broken cloud layer at 800 ft, broken cloud layer at 1600 ft, overcast layer at 2500 ft	3	Light rain, mist	3.3	2.2	93	10	60		End flight 229a due to low ceilings, rain, and snow (1251)

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
0-Aug	1253	Overcast layer at 800 ft	6	Mist	3.3	2.2	93	13	60		
30-Aug	1353	Overcast layer at 1000 ft	10		3.3	1.7	89	15	60		
30-Aug	1453	Few clouds at 1200 ft, overcast layer at 2200 ft	10		3.3	0.6	82	13	50		
30-Aug	1553	Overcast layer at 1800 ft	10		2.8	0	82	13	40		Start flight 229b (1556)
30-Aug	1653	Overcast layer at 1500 ft	10		2.2	-0.6	82	10	50	UAS launch delayed due to poor weather in study area	End flight 229b due to low ceilings, rain, and snow (1721)
30-Aug	1753	Overcast layer at 1500 ft	10		1.7	-1.1	82	10	20		
30-Aug	1853	Overcast layer at 1500 ft	10		1.7	-0.6	85	9	10		
30-Aug	1953	Overcast layer at 700 ft	10		0.6	-0.6	92	9	360		
30-Aug	2053	Overcast layer at 700 ft	10		0.6	-0.6	92	7	340		
30-Aug	2153	Overcast layer at 500 ft	10		0	-0.6	96	9	360		
31-Aug	0753	Overcast layer at 800 ft	10		0.6	-1.1	89	11	310		
31-Aug	0853	Overcast layer at 1100 ft	10		1.1	-1.1	85	16	310		
31-Aug	0953	Scattered cloud layer at 900 ft, broken cloud layer at 1100 ft, overcast layer at 1700 ft	9		1.1	-1.1	85	13	290		
31-Aug	1053	Scattered cloud layer at 900 ft, broken cloud layer at 1100 ft, overcast layer at 1700 ft	5	Mist	1.1	-0.6	89	13	310		
31-Aug	1153	Scattered cloud layer at 900 ft, broken cloud layer at 1500 ft	10		1.7	-0.6	85	14	310		
31-Aug	1253	Scattered cloud layer at 900 ft, broken cloud layer at 1600 ft	10		2.2	-1.1	79	15	310		
31-Aug	1353	Broken cloud layer at 1700 ft	10		2.8	-1.1	76	13	310		
31-Aug	1453	Overcast layer at 1900 ft	10		2.8	-0.6	79	13	310		Start flight 230 (1447)
31-Aug	1553	Few clouds at 1200 ft, overcast layer at 2000 ft	9	Light snow	2.2	0	85	13	320	Start flight 2 (1541)	Flight 230 underway
31-Aug	1653	Broken cloud layer at 1600 ft, overcast layer at 2300 ft	7		1.7	0	89	9	300	Flight 2 underway	Flight 230 underway
31-Aug	1753	Scattered cloud layer at 1300 ft, overcast layer at 1900 ft	10		2.8	0	82	9	290	Flight 2 underway	Flight 230 underway
31-Aug	1853	Overcast layer at 1600 ft	10		2.8	-0.6	79	7	290	Flight 2 underway	Flight 230 underway
31-Aug	1953	Overcast layer at 1500 ft	10		2.8	0	82	11	270	Flight 2 underway	End flight 230 (1947)
31-Aug	2053	Overcast layer at 1500 ft	10		2.8	0	82	10	260	Flight 2 underway	
31-Aug	2153	Overcast layer at 1700 ft	10		2.8	-0.6	79	10	270	End flight 2 (2141)	
1-Sep	0753	Broken cloud layer at 2400 ft, broken cloud layer at 4000 ft	10		2.8	0.6	86	14	170		
1-Sep	0853	Broken cloud layer at 2400 ft, broken cloud layer at 4000 ft	10		2.8	0.6	86	9	160		
1-Sep	0953	Overcast layer at 4500 ft	10		3.3	1.1	86	9	170		Start flight 231 (0926)
1-Sep	1053	Broken cloud layer at 3500 ft, overcast layer at 4400 ft	10		3.9	1.7	86	13	170		Flight 231 underway
1-Sep	1153	Broken cloud layer at 3500 ft, overcast layer at 4400 ft	10		4.4	1.7	82	10	170	Start flight 3 (1144)	Flight 231 underway
1-Sep	1253	Broken cloud layer at 600 ft, overcast layer at 1000 ft	2	Light rain, mist	4.4	3.9	96	9	190	Flight 3 underway	Flight 231 underway
1-Sep	1353	Broken cloud layer at 500 ft, overcast layer at 1000 ft	3	Light rain, mist	5.6	5	96	9	260	Flight 3 underway	End flight 231 (1413)
1-Sep	1453	Broken cloud layer at 1000 ft, overcast layer at 1400 ft	6	Mist	5.6	4.4	93	10	260	Flight 3 underway	
1-Sep	1553	Broken cloud layer at 1000 ft, overcast layer at 1400 ft	10		5	3.3	89	13	270	Flight 3 underway	
1-Sep	1653	Broken cloud layer at 1000 ft, overcast layer at 1500 ft	8		5	3.9	93	8	260	End flight 3 (1703)	
1-Sep	1753	Broken cloud layer at 1000 ft, broken cloud layer at 1400 ft, overcast layer at 1900 ft	9		5	3.9	93	10	270		
1-Sep	1853	Overcast layer at 1200 ft	10		4.4	2.2	86	13	270		
1-Sep	1953	Overcast layer at 1100 ft	10		4.4	2.2	86	10	290		
1-Sep	2053	Overcast layer at 1200 ft	10		4.4	2.2	86	9	280		

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
1-Sep	2153	Overcast layer at 1100 ft	10		4.4	2.8	89	3	270		
2-Sep	0753	Few clouds at 100 ft, scattered cloud layer at 300 ft, overcast layer at 7500 ft	10		2.8	2.8	100	6	120		
2-Sep	0853	Few clouds at 4200 ft, overcast layer at 5500 ft	10	Light rain	3.3	2.8	96	8	130		
2-Sep	0953	Broken cloud layer at 5000 ft, broken cloud layer at 7500 ft	8	Light rain	3.9	3.3	96	10	110		
2-Sep	1053	Broken cloud layer at 500 ft, overcast layer at 4900 ft	10		4.4	3.3	93	10	110		
2-Sep	1153	Broken cloud layer at 500 ft, overcast layer at 4400 ft	10		5	3.9	93	10	120		
2-Sep	1253	Broken cloud layer at 600 ft, overcast layer at 5000 ft	10		6.1	4.4	89	10	110		
2-Sep	1353	Broken cloud layer at 5000 ft	10		7.2	3.9	80	9	110		Start flight 232 (1417)
2-Sep	1453	Broken cloud layer at 5500 ft, broken cloud layer at 7000 ft	10		6.7	3.9	83	11	90		Flight 232 underway
2-Sep	1553	Few clouds at 900 ft, scattered cloud layer at 5500 ft, overcast layer at 7000 ft	10		6.1	3.9	86	13	100		Flight 232 underway
2-Sep	1653	Broken cloud layer at 5500 ft	10		6.1	3.3	83	14	110	Start flight 4 (1642)	Flight 232 underway
2-Sep	1753	Overcast layer at 5500 ft	10		5	3.3	89	16	100	Flight 4 underway	Flight 232 underway
2-Sep	1853	Few clouds at 4700 ft, broken cloud layer at 6000 ft	10		5	2.2	82	14	90	Flight 4 underway	End flight 232 (1850)
2-Sep	1953	Broken cloud layer at 6000 ft	10		4.4	2.2	86	14	100	Flight 4 underway	
2-Sep	2053	No clouds below 12000 ft	10		3.3	2.2	93	11	80	Flight 4 underway	
2-Sep	2153	Overcast layer at 6000 ft	10		2.8	2.2	96	11	90	End flight 4 (2143)	
3-Sep	0753	Vertical visiblity of 200 ft	0.25	Fog	1.7	1.7	100	11	100		
3-Sep	0853	Vertical visibility of 300 ft	0.5	Fog	1.7	1.1	96	11	90		
3-Sep	0953	Vertical visibility of 300 ft	0.5	Fog	1.7	1.7	100	15	100		
3-Sep	1053	*	2		2	2	*	16	90		
3-Sep	1153	Overcast layer at 300 ft	2	Mist	1.7	1.7	100	17	100		
3-Sep	1253	Overcast layer at 300 ft	1.5	Mist	2.2	1.7	96	17	90		
3-Sep	1353	Overcast layer at 200 ft	2	Mist	2.2	1.7	96	15	90		
3-Sep	1453	Overcast layer at 200 ft	2	Mist	2.2	1.7	96	20	90		
3-Sep	1553	Overcast layer at 300 ft	3	Mist	2.2	2.2	100	21	110		
3-Sep	1653	Overcast layer at 300 ft	10		2.2	1.7	96	17	100		
3-Sep	1753	Overcast layer at 300 ft	8		2.2	1.7	96	20	100		
3-Sep	1853	Overcast layer at 400 ft	9		2.2	1.1	92	23	110		
3-Sep	1953	Overcast layer at 400 ft	8		1.7	1.1	96	25	100		
3-Sep	2053	Overcast layer at 400 ft	10		1.7	1.1	96	23	100		
3-Sep	2153	Overcast layer at 400 ft	9		1.7	1.1	96	20	90		
4-Sep	0753	Overcast layer at 600 ft	9		1.1	0.6	96	16	110		
4-Sep	0853	Overcast layer at 500 ft	10		1.1	0	92	23	110		
4-Sep	0953	Overcast layer at 500 ft	9		1.1	0.6	96	24	120		
4-Sep	1053	Overcast layer at 600 ft	10		1.7	0.6	92	25	110		
4-Sep	1153	Overcast layer at 600 ft	9		1.7	0.6	92	22	110		
4-Sep	1253	Overcast layer at 700 ft	10		2.2	0.6	89	24	120		
4-Sep	1353	Overcast layer at 600 ft	10		2.2	0.6	89	23	120		
4-Sep	1453	Overcast layer at 600 ft	10		2.8	1.1	89	20	110		
4-Sep	1553	Overcast layer at 600 ft	10		2.2	1.1	92	22	110		
4-Sep	1653	Overcast layer at 400 ft	9		1.7	1.1	96	21	100		
4-Sep	1753	Overcast layer at 400 ft	9		1.1	0.6	96	18	110		
4-Sep	1853	Overcast layer at 300 ft	9		0.6	0	96	18	110		
4-Sep	1953	Overcast layer at 300 ft	6	Mist	0.6	0	96	21	110		

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
4-Sep	2053	Overcast layer at 200 ft	3	Mist	0.6	0.6	100	20	90		
4-Sep	2153	Overcast layer at 300 ft	1.25	Mist	0.6	0.6	100	16	90		
5-Sep	0753	Overcast layer at 300 ft	0.75	Drizzle, mist	0	0	100	11	90		
5-Sep	0853	Broken cloud layer at 400 ft	0.75	Mist	0	0	100	11	80		
5-Sep	0953	Broken cloud layer at 500 ft	1	Mist	0.6	0.6	100	11	90		
5-Sep	1053	Broken cloud layer at 500 ft	2	Mist	1.1	1.1	100	13	80		
5-Sep	1153	Broken cloud layer at 500 ft	4	Mist	1.7	1.1	96	15	80		
5-Sep	1253	Broken cloud layer at 500 ft	4	Mist	1.7	1.1	96	11	80		
5-Sep	1353	Overcast layer at 500 ft	4	Mist	2.2	1.1	92	13	70		
5-Sep	1453	Overcast layer at 500 ft	10		2.2	1.1	92	13	80		
5-Sep	1553	*	10		2.2	1.1	*	13	90		
5-Sep	1653	*	6		2.2	1.7	*	10	80		
5-Sep	1753	*	7		2.2	1.7	*	11	70		
5-Sep	1853	*	5		2.2	1.7	*	11	80		
5-Sep	1953	*	3		1.7	1.7	*	9	80		
5-Sep	2053	*	1		1.7	1.7	*	9	70		
5-Sep	2153	*	3		2.2	1.7	*	8	70		
6-Sep	0753	Scattered cloud layer at 400 ft, broken cloud layer at 1200 ft, broken cloud layer at 2400 ft	10		3.3	2.8	96	9	70		
6-Sep	0853	Broken cloud layer at 2600 ft	10		3.3	2.8	96	9	80		
6-Sep	0953	Few clouds at 800 ft, overcast layer at 2700 ft	10		3.9	2.8	93	11	80		
6-Sep	1053	Broken cloud layer at 1000 ft, overcast layer at 2800 ft	10		4.4	2.8	89	11	80		
6-Sep	1053	*	10		4	3	*	11	80		
6-Sep	1153	Scattered cloud layer at 600 ft, overcast layer at 2900 ft	10		4.4	2.8	89	10	80		
6-Sep	1253	Scattered cloud layer at 600 ft, overcast layer at 3000 ft	10		4.4	3.3	93	10	90		
6-Sep	1353	Overcast layer at 3100 ft	10		5	3.3	89	7	90		
6-Sep	1453	Overcast layer at 3200 ft	10		5	3.3	89	6	90		
6-Sep	1553	*	10		5	3.3	*	7	100		
6-Sep	1653	*	10		5.6	3.3	*	6	100		
6-Sep	1753	Overcast layer at 3100 ft	10		5.6	3.3	86	0	0	Start flight 5 (1759)	
6-Sep	1853	Overcast layer at 3100 ft	10		3.9	2.8	93	5	60	Flight 5 underway	
6-Sep	1953	Few clouds at 600 ft, overcast layer at 3300 ft	10		3.9	2.8	93	5	20	End flight 5 (1935)	
6-Sep	2053	Scattered cloud layer at 700 ft, overcast layer at 3500 ft	10		3.3	2.8	96	6	70		
6-Sep	2153	Overcast layer at 1300 ft	10		3.3	2.8	96	3	70		
7-Sep	0753	Overcast layer at 1000 ft	10		1.7	0	89	10	320		
7-Sep	0853	Overcast layer at 800 ft	10	Light rain	2.2	0.6	89	8	290		Start flight 233 (0922)
7-Sep	0953	Broken cloud layer at 400 ft, broken cloud layer at 800 ft, overcast layer at 1400 ft	10		2.2	0	85	13	290		Flight 233 underway
7-Sep	1053	Scattered cloud layer at 800 ft, broken cloud layer at 1400 ft, overcast layer at 3400 ft	9	Light rain	2.8	1.1	89	11	290		Flight 233 underway
7-Sep	1153	Broken cloud layer at 1200 ft, overcast layer at 1800 ft	10		3.3	0.6	82	14	280		Flight 233 underway
7-Sep	1253	Broken cloud layer at 1300 ft, overcast layer at 1900 ft	10		2.8	1.1	89	14	290		Flight 233 underway
7-Sep	1353	Broken cloud layer at 1100 ft, broken cloud layer at 1700 ft, overcast layer at 3400 ft	10	Light rain	3.3	1.1	86	15	310		Flight 233 underway
7-Sep	1453	Broken cloud layer at 1000 ft, overcast layer at 1500 ft	10		3.3	1.1	86	15	320		Flight 233 underway
7-Sep	1553	Broken cloud layer at 1200 ft, overcast layer at 1700 ft	10		3.3	1.1	86	14	310		Flight 233 underway
7-Sep	1653	Broken cloud layer at 1000 ft, overcast layer at 1600 ft	10		2.8	1.1	89	18	320		Flight 233 underway

Date	Time	Sky Condition	Visibility (statute miles)	Weather Type	Dry Bulb (C)	Dew Point (C)	Relative Humidity	Wind Speed (knots)	Wind Direction	UAS Activity	Manned Aerial Survey Activity
7-Sep	1753	Overcast layer at 1000 ft	10		2.8	0.6	86	15	320		End flight 233 (1737)
7-Sep	1853	Overcast layer at 1000 ft	10		2.8	0	82	13	320		
7-Sep	1953	Overcast layer at 1400 ft	10		2.2	-0.6	82	11	350		
7-Sep	2053	Broken cloud layer at 1500 ft, overcast layer at 2100 ft	10		2.2	0	85	10	330		
7-Sep	2153	Overcast layer at 1400 ft	10		1.7	-0.6	85	10	340		